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ENVIRONMENTAL RESEARCH

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QUANTIFICATION OF INFILTRATION THROUGH LANDFILL COVERS

R. A. C. PROJECT NO. 440C

Environment
Ontario

6/8/91

ISBN 0-7729-8657-6

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AUGUST 1991

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PIBS 1637
log 91-9600-440

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EXECUTIVE SUMMARY

A set of three lysimeters, identical in design, were installed into filled areas of both the Guelph and Barrie municipal solid waste landfill sites. The Guelph cover consists of a 1.0 m layer of locally available gravelly loam soil overlaid with a 20 cm layer of loam topsoil. The Barrie site on the other hand consists of a 1.5 m thick layer of sand. The aim of the study was to install lysimeters into landfill covers differing in soil texture and subsequently to measure the through-cover infiltration captured below.

The lysimeter design was based on prototypes constructed and tested in previous studies. The lysimeters installed in this study measured 3 m by 3 m in surface area and were positioned 1.0 m into the waste beneath the cover. Lysimeter side walls extended 0.3 m into the overlying cover. The landfill cover material over each lysimeter was excavated to enable lysimeter construction and then replaced, with care taken to ensure that the material was restored to the same dry bulk density, as it was prior to excavation. Lysimeter installation was complete at both sites by December 1989.

Infiltration rates were monitored for one year (12 months) at both sites. Two techniques were used for measuring the volume of infiltrated water collected in the lysimeter storage zones. Later, the techniques were evaluated for their accuracy and ease of application.

In addition to measuring the through cover infiltration generated by natural precipitation (including snow-melt), tests were conducted in the field to simulate infiltration events in order to assist the analysis of monitored lysimeter infiltration measurements. By applying a known volume of infiltration water to the landfill cover over the lysimeters, and by establishing initial and boundary conditions, theoretical infiltration volumes could be calculated. Calculated theoretical infiltration volumes were compared with actual lysimeter measurements for each simulated event. The results were in close agreement.

A computer simulation of through-cover infiltration at each site was also conducted to test the utility of the Hydrologic Evaluation of Landfill Performance (HELP) Model as a tool for predicting infiltration through landfill covers of differing textures and configurations. The HELP model was applied to both the Guelph and Barrie sites and the computer results were compared to the lysimeter-measured results.

Findings

1. In constructing the lysimeters, a strict protocol must be followed to ensure that all the lysimeters are built the same to produce reliable data, and to assist in conducting the future monitoring tasks.

2. The lysimeters are capable of withstanding rubber-tired backhoe traffic over their surface following the addition of a 0.9 m layer of cover material.

3. Direct volumetric measurement by monthly pumping proved to be the most efficient and accurate means of measuring the monthly volumes of infiltration water. Water level recording charts, the other approach considered and evaluated, did, however, provide a means for identifying trends in the rate of infiltration within a month or within a season.

4. During the field infiltration simulation tests, 94 percent of the infiltration expected to occur at the Guelph site under controlled conditions was collected by the lysimeter. Similarly for the Barrie site, 99 percent of the calculated infiltration was measured by the lysimeter.

5. During 1990, 26 percent of the precipitation that fell on the Guelph site became through-cover infiltration.

6. During 1990, 67 percent of the precipitation that fell on the Barrie site became through-cover infiltration.

7. The computer simulation gave mixed results. The Guelph simulation estimates of annual infiltration were 15 percent higher than what was actually measured. The Barrie simulation estimate of annual infiltration was approximately one-half of what was actually measured. In both cases, the general "shape" of the computer-generated annual accumulated infiltration curve was quite similar to that generated from lysimeter monitoring data.

Recommendations

The following recommendations are drawn from the study findings. It is recommended that:

1. The lysimeters constructed and monitored in this study continue to be monitored in order:
    - to increase the infiltration dataset,
    - assess the long-term performance of earthen landfill covers, and
    - evaluate the long-term reliability of the lysimeters for use as an infiltration measurement tool.

2. Monthly pump-out of the lysimeter storage zones be the primary means of determining infiltration volumes. Chart recorder data is necessary only if general trends with respect to the rate of through-cover infiltration within any given month is desired.

3. Similar lysimeters be installed on other landfills of differing cover textures and configurations to expand the available database on through-cover infiltration.

4. Installation of lysimeters at all sites be consistent, following a prescribed protocol, to enable comparison of data among sites and to simplify monitoring tasks.

5. Landfill operators be trained in the task of routinely monitoring the lysimeters and recording observations in order to economically acquire a large database on through-cover infiltration.

6. The expanded database be used to refine and/or create an appropriate model suitable for use in designing landfill covers.

ACKNOWLEDGEMENTS

The following are members of the study team who combined their skills to complete the investigation described in this report:

K.J. McKague, P.Eng. (Ecologistics Limited) - Project Manager/Co-investigator
J.H. Cuthill (Harmony Planning Consultants) - Co-investigator

The study team thanks the following study participants for their valuable contribution to the assignment:

R.A. McBride - for his critique of the methodology used to conduct the field infiltration simulation tests.

Mr. Paul McLennan, Mr. Colin Read and Mr. Dereck Veenhoff for their dedicated and capable assistance during lysimeter construction.

Personnel at the Guelph landfill site and with the City of Guelph for providing logistical support and who were very helpful in providing maintenance required for the study area.

Personnel at the Barrie landfill site and with the City of Barrie for providing logistical support and who were instrumental in assisting with the cover construction, providing access to the site and in assisting with monitoring and maintenance of the study area.

C.A. Bostock - Environment Ontario's liaison officer for this project, whose direction in the study provided efficient co-ordination of the work.

1.0 INTRODUCTION

1.1 Background

Decommissioned municipal solid waste landfill sites often rely exclusively on the use of an earthen cover to restrict the access of precipitation to the underlying refuse material. While some infiltration of precipitation into the cover is desirable for sustaining vegetative growth on the site, excess infiltration water which percolates beyond the soil storage zone and enters the buried waste can accumulate in the landfill. leach wastes into groundwater, and accelerate landfill subsidence. "Consequently, the successful performance of the entire landfill is very much a function of interactive processes operating to control water balance within the landfill cover" (Nyhan, J.W., T.E. Hakonson and B.J. Drennon, 1990).

The following quote from Nyhan, Hakonson and Drennon (1990) gives the basis of one of the Ministry's main interests in quantifying landfill cover infiltration.

> Very little field data are available where the leachate term of the water balance equation has been directly measured for a landfill profile. The approach generally taken is to measure evapotranspiration, precipitation, runoff, and the changes in soil water storage and to estimate leachate production by the difference. However, small errors in the estimation of evapotranspiration can result in a dramatic error in estimating leachate production using this procedure.

As an alternative, it has been proposed that lysimeters be installed in landfills where information with respect to infiltration rates is desired. The lysimeters provide a means of directly measuring that portion of soil moisture which passes through a landfill cover into the underlying waste. Previous studies have been undertaken in Ontario to evaluate prototypes of an economical field-scale lysimeter suited to installation in a landfill cover (Gartner Lee Associates Ltd., 1985 and Ecologistics Limited, 1990). The lysimeters installed and monitored in this study are slightly modified versions of prototypes previously studied by Ecologistics Limited (1990).

1.2 Study Objectives

Four objectives were identified for this study. They are:

1. Install a set of three (3) lysimeters into each of two (2) decommissioned sites. These two sites are to differ with respect to the textural characteristics of the soil cover material.

2. Acquire a dataset of volumes and rates of through-cover infiltration for the covers of differing soil texture being considered in the study.

3. Conduct in-field infiltration simulation experiments to verify the satisfactory operation of the installed lysimeters.

4. Modify an existing United States - Environmental Protection Agency (US-EPA) landfill cover water budget/leachate generation model to facilitate its use in Ontario. Evaluate the computer model's usefulness as a tool for predicting cover infiltration rates.

To achieve these objectives, the study team completed a number of specific tasks. These tasks included:

- identifying and selecting suitable study sites,
- constructing lysimeters at the study sites,
- installing the lysimeter monitoring apparatus,
- monthly pumping of accumulated infiltration water from each lysimeter's storage zone, with the volume of water pumped out measured and recorded,
- maintaining chart recorders which were installed to continuously monitor the water level in each of the lysimeter storage zones,
- completing a series of infiltration simulation tests on one lysimeter at each site using an apparatus constructed on-site,

- preparing climatic data input files for a cross-section of towns/cities across Ontario,
- modifying the HELP software to accept Ontario climatic data,
- employing the HELP software to simulate conditions at sites where the lysimeters were installed, and
- comparing the field-measured data with the computer simulated data.

2.0 THE LANDFILL LYSIMETERS

2.1 Lysimeter Description

A cross-sectional representation of the lysimeters installed in the study is shown in Figure 2.1. These lysimeters can be classified as filled-in lysimeters, as opposed to monolith lysimeters given that the landfill cover above the lysimeters was disturbed and then replaced during lysimeter construction. They are termed free-draining lysimeters given that they drain freely to the atmosphere by accumulating infiltration water in a storage chamber below the soil mass. Deep infiltration water gathered in the lysimeter's storage zone is measured volumetrically which is in contrast to some lysimeters which account for additions or losses to the lysimeter by measuring changes in the weight of the lysimeter through time.

The lysimeter shown in Figure 2.1 has a 9 m^2 surface area. It has been shown that for valid 10-day or monthly values, free-draining lysimeters which have a surface area of 4 m^2 or greater provide reliable data. (Aboukhaled, A., A. Alfaro and M. Smith, 1982). Other aspects of the lysimeter design worth noting are as follows:

- A flexible 40 mil prefabricated PVC liner material forms the lysimeter walls and floor.

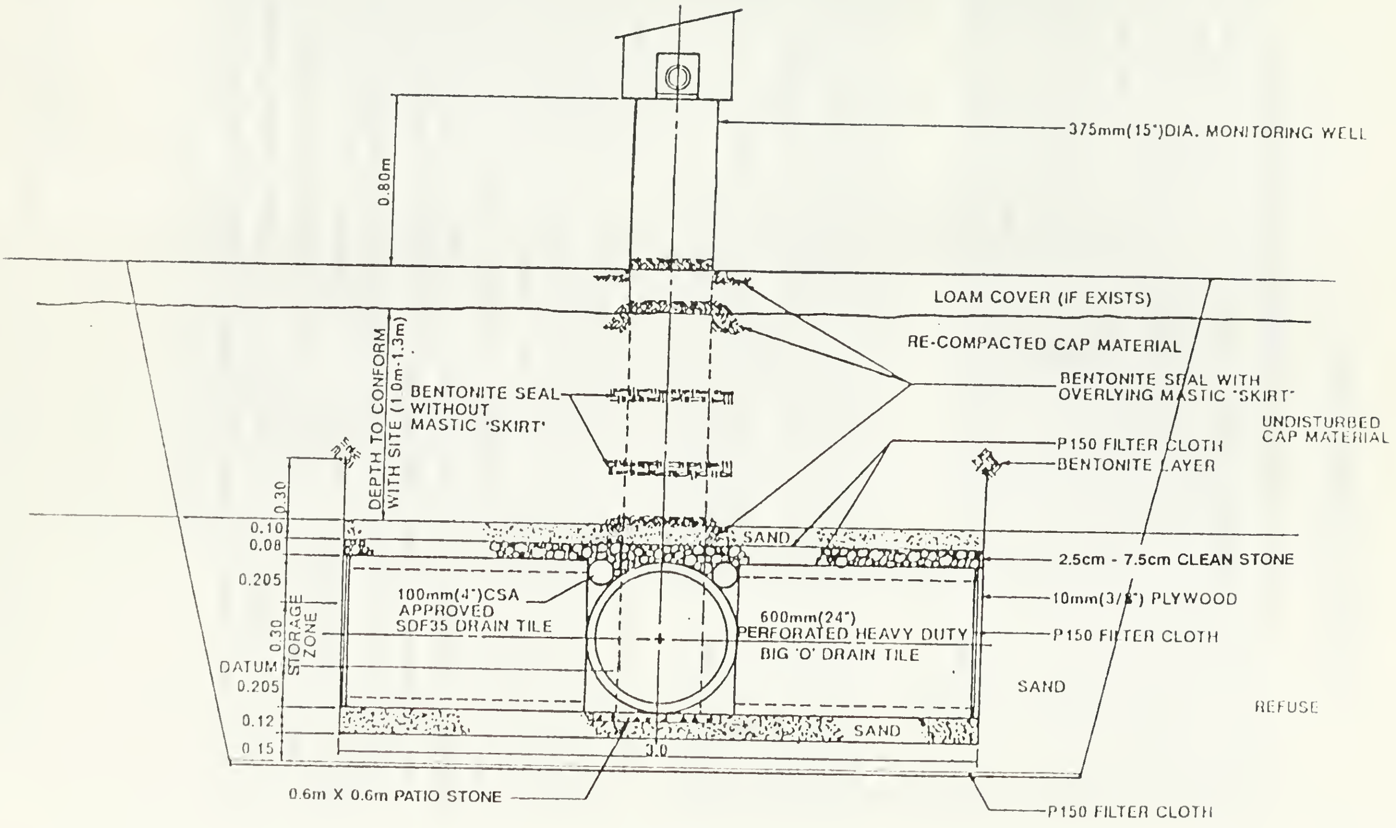
- Perforated 600 mm dia. Big "O" heavy duty drainage tile forms the storage zone. This provides ample storage capacity and facilitates the incorporation of a flexible storage datum.

- A 380 mm dia. well, located in the centre of the lysimeter, provides access to the lysimeter's storage zone for pumping out captured infiltration. It also acts as a stilling well for the float-and-pulley type water-level recorder, used to obtain a continuous record of storage zone additions.

- Slots cut in the monitoring well within the lysimeter's storage zone, (i.e. the bottom 0.8 m of the monitoring well pipe), provide rapid air and water exchange between the storage zone and the monitoring well.

- A Mel-rol membrane and mastic skirt, together with bentonite, are used to prevent preferential flow along the monitoring well.

FIGURE 2.1: LYSIMETER CROSS-SECTION



2.2 Description of Installation Sites

With logistical assistance received from the Ministry's assigned liaison officer, approval was obtained from the appropriate authorities to install the lysimeters on the Guelph and Barrie landfill sites. The Guelph site is located on the eastern outskirts of the city, with access off of Eastview Road. Textural analysis of a composite sample revealed the Guelph cover to be a gravelly loam material (see Table 2.1). The cover was compacted during installation. Measured dry bulk densities associated with the completed cover ranged from 1.7 Mg/m^3 to 2.3 Mg/m^3. The Barrie site, located just west of the city off an access road that extends to Ferndale Avenue, uses locally available sand as the cover medium (see Table 2.1). Final dry bulk densities of the cover as installed at Barrie are in the order of 1.8 Mg/m^3.

The textural characteristics of the covers at the Guelph and Barrie sites are distinctly different from each other and from the texture of the cover at the Britannia Road Landfill site, which had lysimeters installed in a previous study (Ecologistics Limited, 1990). Thus observation of the levels of infiltration over a range of cover textural characteristics would be possible through this choice of sites.

The exact area chosen for lysimeter installation at both the Guelph and Barrie landfill sites were similar with respect to slope position and were at a similar stage with respect to cap installation. The set of three (3) lysimeters were installed at both sites near the top of the landfill. The top of the landfill was chosen in order to facilitate construction on a relatively flat shelf and to minimize the chance of complications during the monitoring and field simulation components of the study. By choosing an upslope and relatively flat portion of the landfill for lysimeter installation a "worst case" scenario was considered. More infiltration than surface runoff could be expected on such a landscape position. As well, the chance of underground seepage was avoided. Also in choosing this slope position it was easier to minimize runoff losses during the field infiltration experiments. Finally, because the lysimeters were located on similar landscape positions, comparison of the results gathered at the Guelph and Barrie sites would be possible.

Table 2.1

Textural Analysis of the Cover Material at the Study Sites

CONSTITUENT	DIAMETER LIMITS[1] (mm)	PERCENT BY WEIGHT	
		Barrie Landfill Cap	Guelph Landfill Cap
Gravel	>2.00	0	37
Very coarse sand	2.00 - 1.00	2.5	3.7
Coarse sand	1.00 - 0.50	10.8	5.0
Medium sand	0.50 - 0.25	36.6	7.8
Fine sand	0.25 - 0.10	37.9	19.9
Very fine sand	0.10 - 0.05	6.1	13.7
Total sand	2.00 - 0.05	93.9	50.1
Silt	0.05 - 0.002	3.6	40.4
Clay	<0.002	2.4	9.6
Textural class[1]		Sand	Gravelly loam

The lysimeters were installed at both the Guelph and Barrie sites in a location where the final cover was still being installed and thus final grading had not yet taken place. For Guelph, this meant that, while the 1.0 m thick landfill cap had been applied at the time of lysimeter installations, the final 0.2 m loam cover or topsoil layer applied to support vegetative growth had not been added. Seeding had also not yet been completed. At Barrie, a shallow sand covering was over the area at the time lysimeters were installed. The final 1.5 m thick sand cover complex however, was not yet complete. With portions of the cover at both sites being applied following lysimeter installation, and with the ability of the lysimeters to withstand heavy equipment traffic, an improved situation existed to help ensure that cap and cover characteristics over the installed lysimeters were similar to those existing within the surrounding monolith.

---

[1] *Classification is based on the United States Department of Agriculture's Soil Classification System.*

2.3 Lysimeter Installation

Installation of the lysimeters at both sites was undertaken in September 1989. A rigid protocol was followed during construction. A detailed written and pictorial account of the lysimeter installation is provided in Appendix A. A summary account of the installation steps is provided here. Installation began by excavating a 4 m x 4 m hole in the landfill cap. The depth of the hole was dictated by the final cover depth. This was due to the fact that the lysimeters were installed in the underlying garbage to a depth which resulted in the side walls of the lysimeter extending only 0.3 m (1 foot) into the overlying cap. As the cap was excavated, densities of the cap were taken at 15 cm (6 inch) intervals using a CPN Corporation, model MC-1, moisture/density gauge. These densities were used as a reference for restoring the cap as close as possible to its original condition when replacing the cap material over the lysimeter. All pertinent elevations associated with the lysimeters such as the elevation of the patio stone at the base of the well were recorded and referenced to a known benchmark.

Water level recorders including the shelter boxes were positioned on top of each lysimeter's monitoring well following lysimeter construction. As well, each lysimeter's storage zone was filled with water to test for leaks. When no leaks were detected, the water was then pumped down to a pre-determined datum (see Figure 2.1).

The Guelph lysimeters were fully functional by December 1989, while the Barrie lysimeters were fully operational by January 1, 1990. The landfill covers themselves, however, were not fully completed. The final loam cover and seeding on the section of the landfill where the lysimeters were installed was completed at Guelph in April 1990. The 1.5 m deep sand cover over the area where the lysimeters were installed at Barrie was applied in November 1989 and supplemented with 15 cm of sand in June 1990. No seeding has been completed to date at Barrie. This conforms to the normal maintenance routine at the Barrie site. Some vegetation is expected to establish naturally with time.

3.0 MONITORING THE LYSIMETERS

3.1 Monitoring Techniques

Following lysimeter installation, a comprehensive monitoring program was implemented in order to fully assess lysimeter operation and accurately measure the volumes of through-cover infiltration collected in the lysimeter's storage zone. Two techniques were employed in quantifying the volume of infiltrated water collected. One technique relied on pumping out, the water that had collected in the storage zone. This was undertaken on a monthly basis. The procedure employed a submersible pump equipped with a metal cage footing (see Figure 3.1). This assembly was lowered into the monitoring well and set on the well's patio-stone base. This was the same pump and associated stand that were described earlier. By always using this apparatus, a constant datum within each lysimeter's storage zone was used throughout the study. The water pumped out was measured using a flowmeter. The total volumes measured by the flowmeter were further verified by discharging the pumped water into a graduated 200 L barrel. In this way the flowmeter was also calibrated.

In addition to the direct volumetric measurements, as described above, a second indirect technique using a Leopold-Stevens (float-and-pulley type) water-level recorder was also used. This approach provided a continuous record of water additions to the lysimeter storage zone. The water-level recorder was set for a 32 day clock rate.

Previous work with a similar recording set-up for measuring the water level in the lysimeter's storage zone found that converting the change in well levels to a volumetric equivalent required precision in the operation and maintenance of the chart recorders as well as an extremely accurate stage-storage curve for the storage zone which relates the volume of water in the well to the height of water in the well. The precision needed when using a water-level recorder to measure infiltration, may limit this technique somewhat as a tool for use in routine monitoring. The actual volumes pumped out of the lysimeters each month indicated the degree of error possible when basing the calculation of monthly recharge only on the associated rise in water level in the lysimeters.

Figure 3.1 The Submersible Pump Attached to a Metal Stand Used for the Monthly Pump out of Each Lysimeter's Storage Zone

Despite the evident weakness' of the water-level recorders to measure actual infiltration volumes, the recorder's response curves generated by this technique do provide a representative record of the timing of infiltration events into the lysimeter storage zones. Therefore, chart records were reviewed to identify rates of infiltration and trends in infiltration rates within seasons. Moreover, individual precipitation or snowmelt events were reviewed to determine if all lysimeters at the respective sites were responding in a similar manner.

3.2 Lysimeter Calibration

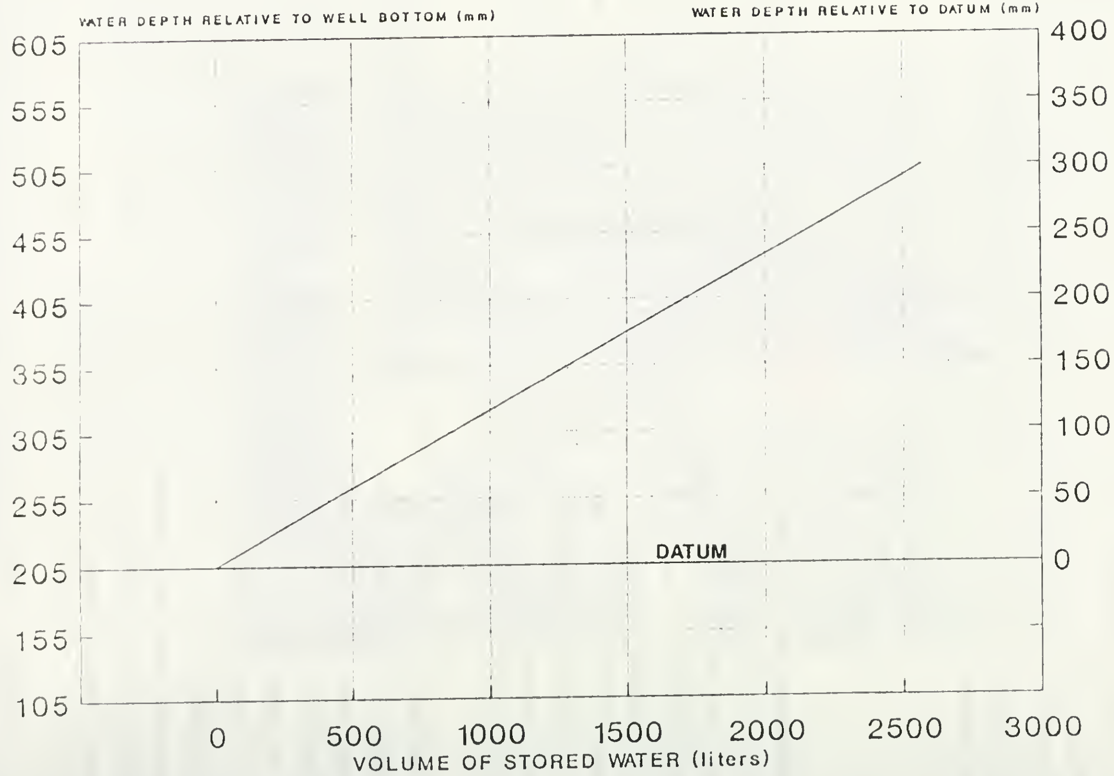
Lysimeter calibration refers to the development of a stage-storage relationship for the lysimeter which is used to convert the change in water level in the lysimeter's storage zone to a volume of water added to the storage zone. It was concluded that a mathematical approach to developing a stage-storage relationship for the storage zone would be appropriate given that the storage zone of the installed lysimeters consisted primarily of uniform pipe, that the exact location of the storage zone datum was known and that lysimeter walls were kept vertical during lysimeter construction. Later, when monthly pump-out data was available, the mathematical approach to the calibration curve was verified for its accuracy.

The storage zone occupies a region in the well that extends from 205 mm above the lysimeter's base patio stone to 505 mm above the patio stone. The mathematical approach used assumed the zone to be a 3.0 m x 3.0 m box 300 mm deep. The volume occupied by the drainage pipe, plywood and stone in the zone was then subtracted from this total volume to arrive at the actual amount of void space available in the storage zone. Calculations indicated that the storage zones have an average porosity of approximately 95 percent. Further, porosity was found to be slightly higher in the storage zone along the horizontal centreline of the 600 mm dia. Big "O" tiles and decreased with vertical distance from the centreline. Porosity calculations were completed for 5 cm intervals within the storage zone.

The stage-storage relationship or calibration curve for all the lysimeters is shown in Figure 3.2. Given the high and relatively consistent porosity of the storage zone and the geometric simplicity of the storage zones configuration, the calibration curve approximates a straight line. The data used to generate this graph are presented in

FIGURE 3.2

STAGE-STORAGE CURVE FOR LYSIMETERS
(CALIBRATION CURVE)



MATHEMATICALLY DERIVED

tabular form in Appendix B. This tabulated version of the stage-storage relationship which lists the changes in accumulated volume for each millimetre change in water level above the storage zone datum is perhaps the most useful tool in converting changes in well level to volumes. The curve was used for all lysimeters given that all lysimeters were constructed in the same manner.

Water volumes pumped out were used to verify the accuracy of this mathematical approach to developing a stage-storage relationship. It is recognized that a mathematically-derived stage-storage relationship could be inaccurate if assumptions made to simplify the math were in error. Similarly, errors could also exist from field-measured data. Errors in the field could arise from measurement errors or simply a lack of accuracy in the measuring tools themselves. It is thought that if both approaches provide similar results, a high degree of confidence could exist with either of the techniques. Table 3.1 compares pumped-out data versus the mathematically-derived calibration curve output for Guelph lysimeter #2. The two approaches to calibration provided similar results and thereby instilled confidence in the mathematically-derived stage-storage curves.

Table 3.1

A Comparison of Stage-Storage Curves Developed Using a Mathematical Approach Versus a Field-Measured Approach

Water Level Above Datum (mm)	Accumulated Volume in Storage Zone	
	Calibration Curve (L)	Field-Measured (L)
0	0	0
10	85	80
30	256	280
50	426	480
80	684	680
100	856	880
125	1071	1090

4.0 MONITORING RESULTS

Following installation, the lysimeters were monitored for the 1990 calendar year in order to quantify the amount of infiltration which passed through the landfill covers. Changes were made to the landfill cover at both sites during the period of monitoring. At the Guelph site, in April 1990, the final loam topsoil layer was spread and grass seed was applied to complete the landfill cover. Just prior to this final loam cover application, the study team took survey readings in the vicinity of the lysimeters, as well as on each lysimeter's base patio stone to determine if any settlement or movement of the lysimeters had occurred over the winter months. By relating the readings back to a permanent benchmark established at the site during lysimeter construction, it was concluded that no movement or shifting of the lysimeters had occurred at the Guelph site.

A different situation existed at the Barrie landfill site. The entire cover was applied to the site after the lysimeters were installed. While most of the cover was applied during the late fall of 1989 and early winter 1990, it was not completed until June 1990. When the study team re-surveyed the Barrie lysimeters in September 1990, it was found that the lysimeters dropped approximately 0.3 m from their original installation elevation. This change drop is thought to have been a consequence of the entire cell settling from the addition of sand over unconsolidated trash and not simply due to a shifting of the lysimeters. The added weight of the sand cover could easily cause this much settlement. No problems have been encountered with the lysimeters themselves as a consequence of this settlement, further showing their ability to accommodate site settlement which can be expected with a landfill over time.

4.1 Monthly Volumetric Measurements, 1990

The lysimeters at both sites were pumped out monthly and the volumes pumped out were measured as described in Section 3.1. Figures 4.1 and 4.2 graphically illustrate the data obtained from this monthly monitoring procedure for the Guelph and Barrie sites, respectively. The volumes pumped out are shown in contrast to the total precipitation for the same month. The precipitation data shown was not recorded directly on site. Instead, precipitation records were used from the closest Environment Canada Atmospheric Environment Service (AES) climatological station. For the Guelph site,

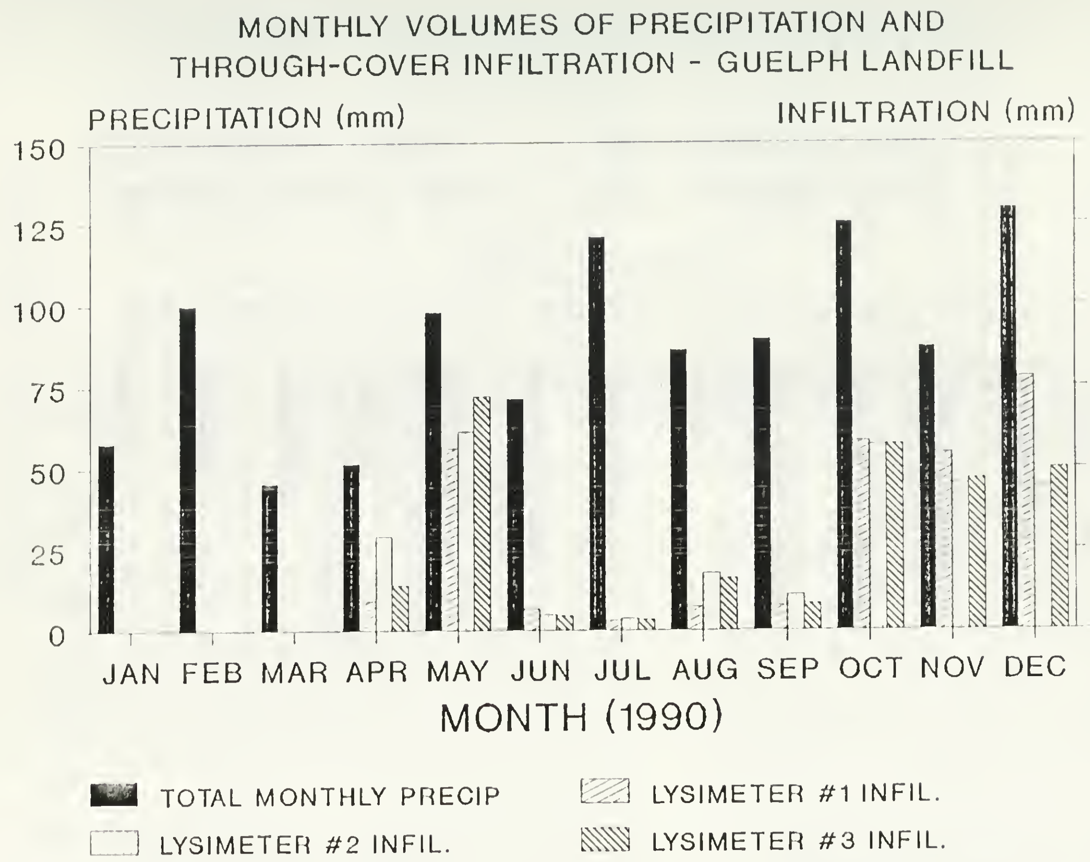

MONTHLY VOLUMES OF PRECIPITATION AND THROUGH-COVER INFILTRATION - GUELPH LANDFILL
PRECIPITATION (mm)
INFILTRATION (mm)
150
125
100
75
50
25
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH (1990)
TOTAL MONTHLY PRECIP
LYSIMETER #2 INFIL.
LYSIMETER #1 INFIL.
LYSIMETER #3 INFIL.

FIGURE 4.1

MONTHLY VOLUMES OF PRECIPITATION AND THROUGH-COVER INFILTRATION - BARRIE LANDFILL

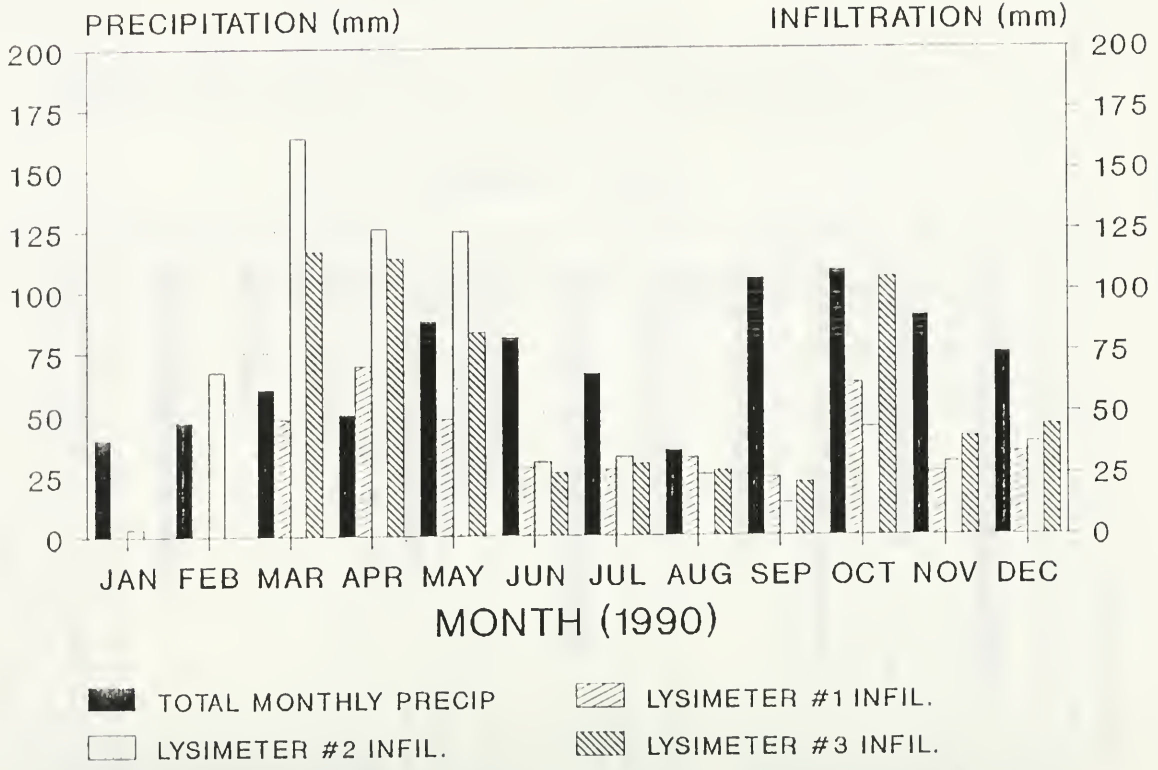


FIGURE 4.2

this was the Guelph arboretum station. For Barrie, the Barrie WPCP station was used.

In November 1990 the Guelph arboretum data was not available due to equipment malfunction. Consequently the Waterloo-Wellington Airport station data had to be used.

For the calendar year 1990, the through-cover infiltration volumes measured at the Guelph site amounted to 25.8 percent of the total precipitation that fell during the same period. This represents 274.3 mm (10.8") of infiltration. For the Barrie site, the measured through-cover infiltration was a much higher fraction of the total precipitation. Sixty-seven (67) percent of the year's total precipitation was captured as through-cover infiltration. This converts to 566.2 mm (22.3") of infiltration. Both these fractions represent the average of the volumes captured by the three (3) lysimeters installed on the two sites. Monthly variations among lysimeter can be seen in Figures 4.1 and 4.2. A detailed tubulated account of the infiltration volumes captured is provided in Appendix C.

The volumetric data collected shows that the sand cover at Barrie allowed 2.6 times more of the available precipitation water to enter the underlying cap material than did the gravelly loam cover at the Guelph site. Much of this difference occurred during the first five months of the year. It was during this time that the cover material at the Barrie site was being installed and when much of the site settlement occurred. The cover, when installed, may have had a high moisture content. With some of the cover being applied over the winter the opportunity also existed for snow to be trapped in layers within the cover. This water would eventually drain during the spring thaw period.

After May, the levels of infiltration at the Barrie site were less variable. If infiltration volumes for the period of June through December is compared then the Barrie cover allowed just 1.6 times more of the available precipitation water to pass through than the Guelph cover did in the same period. Note as well, however, that Barrie received 21 percent less rainfall in the same period and for the year in general.

4.2 Continuous Well Level Recordings, 1990

Water level recorders installed over each lysimeter's monitoring well provided a continuous record of water height in the lysimeter's storage zone. This enabled tracking

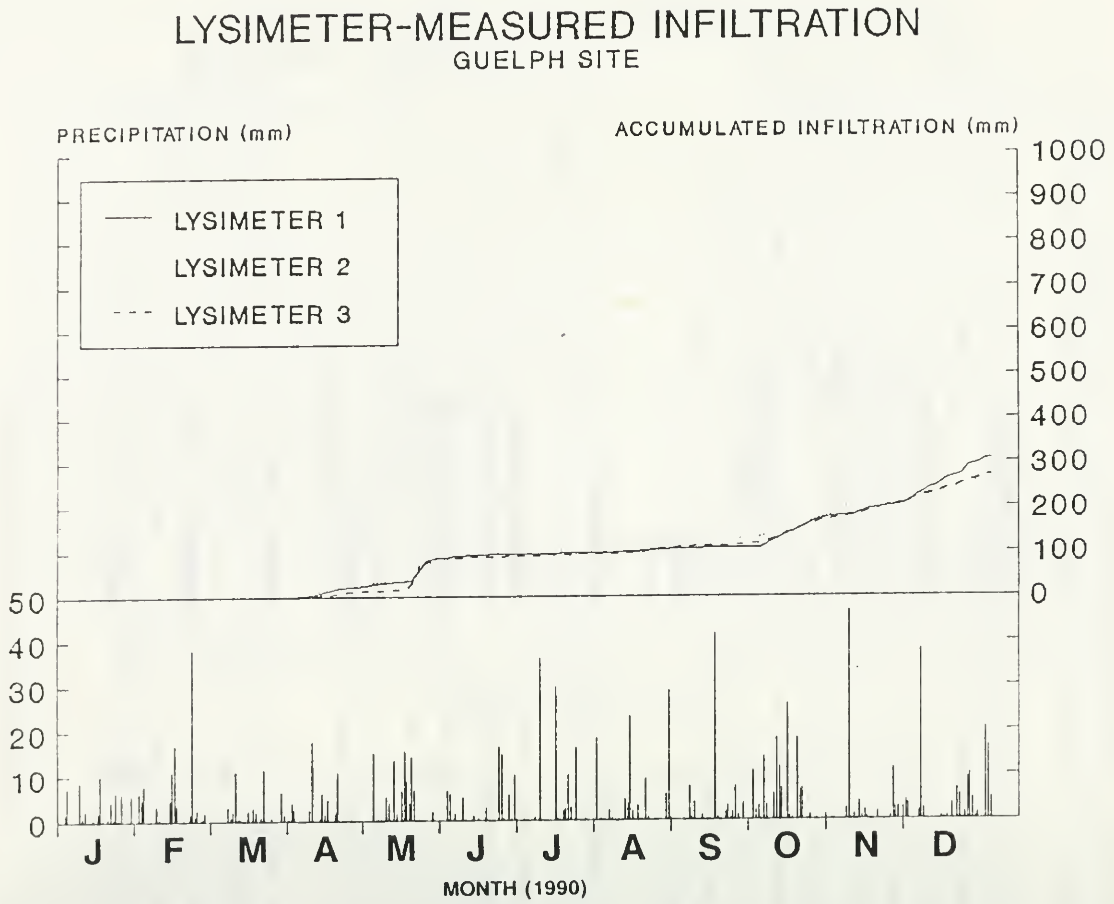

LYSIMETER-MEASURED INFILTRATION
GUELPH SITE
PRECIPITATION (mm)
ACCUMULATED INFILTRATION (mm)
LYSIMETER 1
LYSIMETER 2
LYSIMETER 3
1000
900
800
700
600
500
400
300
200
100
0
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH (1990)

FIGURE 4.3

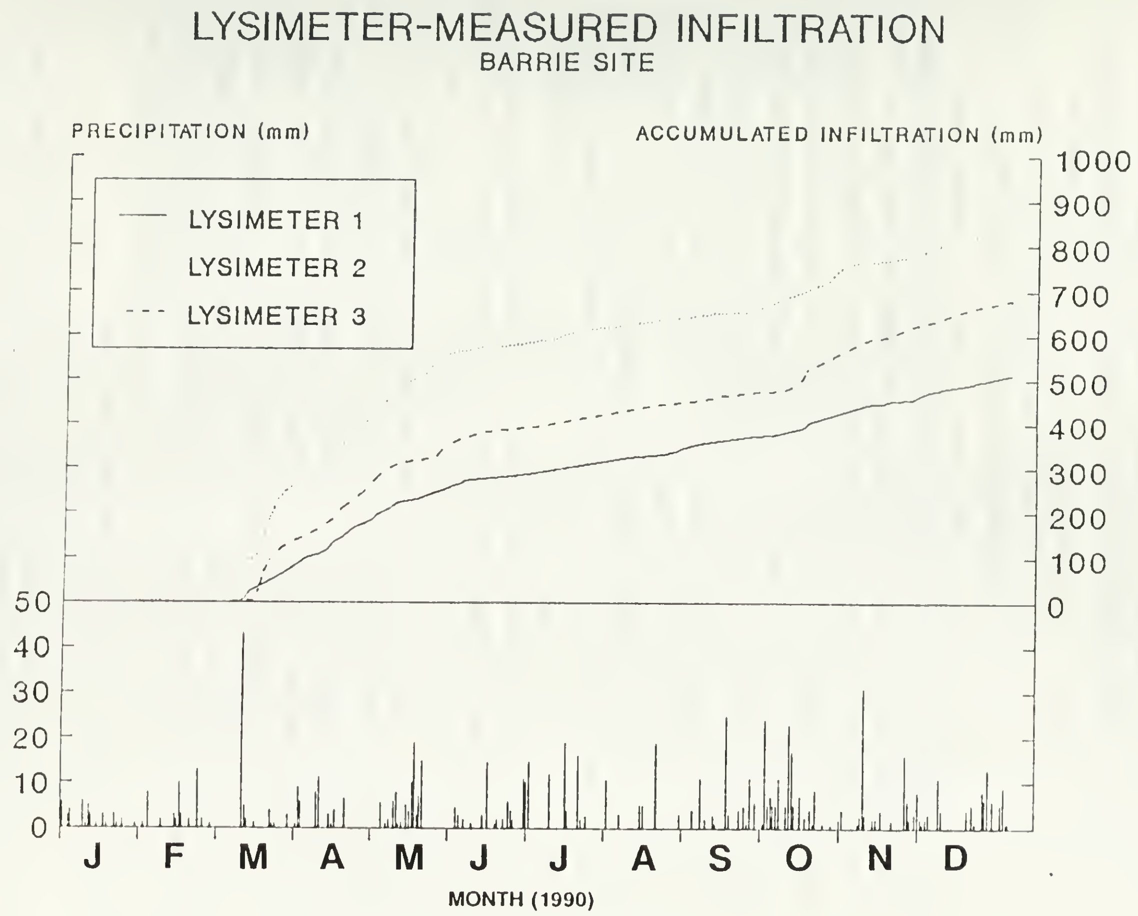

LYSIMETER-MEASURED INFILTRATION
BARRIE SITE
PRECIPITATION (mm)
ACCUMULATED INFILTRATION (mm)
LYSIMETER 1
LYSIMETER 2
LYSIMETER 3
1000
900
800
700
600
500
400
300
200
100
0
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH (1990)

FIGURE 4.4

of the timing of infiltration additions to the storage zone within each month and assisted in determining the rate of infiltration during seasons of the year. Figures 4.3 and 4.4 present the recorded water level data. This plotted water level data is also provided in tabular format in Appendix D. The data presented shows a continuous cumulative record of infiltration for both sites in 1990 and has been adjusted to account for the porosity within the storage zone as was described in Section 3.2. As well, the y-axis scales have been made identical to each other to assist in visually comparing results between the Guelph and Barrie sites. Rainfall measured at the selected nearby weather station has also been added at the bottom of the graph to assist in identifying any possible relationships between precipitation and infiltration rates. Finally, an estimate, rather than the actual measurement, was used to provide a continuous infiltration record for the period the field simulations were being conducted over lysimeter #2 at each site. The estimate was taken to be the average volume of infiltration recorded during the simulation period by lysimeter 1 and 3 at the same site. An additional complication arose at the Barrie site during the monitoring period. The lysimeters were vandalized on October 13. The paper charts were damaged and the floats removed from the recorder pulleys and discarded in the bottom of the monitoring well. About two weeks of data was lost from each lysimeter at Barrie because of this mishap. Estimates of well water level were made using the volumes of water pumped out of each lysimeter for that same period in order to provide the continuous line graphs shown in Figure 4.4.

As can be seen from Figure 4.1, the lysimeters at the Guelph landfill gave nearly identical responses in terms of the timing of infiltration. Essentially no infiltration occurred during the winter when the cover was frozen. A significant input occurred in mid-May immediately following a short period when rainfall occurred every day. Little infiltration occurred during the late spring and summer when evapotranspiration losses are known to be at their peak. By fall, however, infiltrating water was recorded to be slowly, yet steadily, entering the storage zone. Large rainfall events seemed to have little observed effect on the timing of infiltration. Wet periods during the year, however, were seen to affect the shape of the accumulated infiltration curve.

Lysimeter response at the Barrie landfill was not as consistent among lysimeters as was observed at the Guelph site, particularly during the first part of the year. This can be explained by the fact that the cover was not fully in place on the site until June as was described earlier (see Section 4.1). From June through December, however, the water levels in each lysimeter are seen to more closely match each other. A large rainfall event on March 11 appears to have influenced infiltration. Except for this March 11, event, the trend, as with Guelph, is that wet periods in a season rather than specific storm events can be seen to affect the volume of infiltration through the landfill cover.

4.3 Assessment of Monitoring Techniques

In monitoring similarly designed lysimeters under a previous study (Ecologistics Limited, 1990), the study team had some concern over the measurement accuracy that resulted from using the water level records combined with the stage-storage relationships for determining the volumes of infiltration water collected by the lysimeters. Unfortunately, in that previous work, direct monthly volumetric measurements were not available to compare with values obtained using the well level data. Enough information, however, has been collected here to facilitate such a comparison and identify the error, if any, associated with estimating volumes from changes in well water levels. Table 4.1 compares the monthly pumped-out volumes with the well level estimates for the same period. The percent difference between the volume obtained using these two approaches is also shown.

On a monthly basis the margin of error possible in converting the change in well level to a volume is quite variable. For some of the winter months when no infiltration occurred, there was no difference between the two methods. The monthly error, when infiltration occurred, however, ranged from as little as 0 percent to as high as 175 percent error. When infiltration measurements are considered on an annual basis, the range in error using the well level data ranged from 0 percent to 21 percent. The average error resulting from estimating infiltration volume from water level data when all three lysimeters were considered over the year was 5 percent for the Guelph site and 15 percent for the Barrie site. Such an error in measurement can be significant, especially when infiltration rates are low.

Monthly pumping to a known datum and measuring the pumped out volume such as was done in this study is relatively quick and convenient and can ensure that the data collected is accurate. The only advantage seen to using the water level recorders is their ability to illustrate the relative timings of infiltration through the cover.

Table 4.1
A Comparison of Monitoring Techniques

	GUELPH INFILTRATION												BARRIE INFILTRATION											
	Measured Volumes (L)[1]				Estimated Volumes (L)[2]				% Error				Measured Volumes (L)[1]				Estimated Volumes (L)[2]				% Error			
Month (1990)	1	2	3	AVG	1	2	3	AVG	1	2	3	AVG	1	2	3	AVG	1	2	3	AVG	1	2	3	AVG
January	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	9	0	22	0	7	0	21	0	7
February	0	0	0	0	0	0	0	0	0	0	0	0	0	602	0	201	0	680	0	227	0	13	0	4
March	0	0	0	0	0	0	0	0	0	0	0	0	428	1470	1048	982	592	1777	1326	1232	38	21	27	29
April	80	260	124	155	220	299	107	209	175	15	14	35	625	1132	1023	927	859	1304	1182	1115	37	15	16	23
May	505	550	648	568	543	594	657	598	8	8	1	5	431	1120	748	766	659	1303	794	919	53	16	6	25
June	60	42	40	47	85	21	46	51	42	50	15	9	249	270	230	250	192	199	241	211	23	26	5	18
July	26	33	30	30	28	28	36	31	8	15	20	0	234	290	265	263	258	294	231	278	10	1	6	6
August	66	-[3]	142	104[5]	68	-[3]	137	103[5]	3	-[3]	4	0[5]	286	222	238	249	339	213	257	270	19	4	8	10
September	67	-[3]	72	70[5]	32	-[3]	71	52[5]	52	-[3]	1	26[5]	212	-[3]	196	204[5]	192	-[3]	189	191	9	-[3]	4	7
October	523	514	515	517	622	458	515	532	19	11	0	3	562	-[3]	950	756[5]	594	-[3]	999	797	6	-[3]	5	6
November	491	404	420	438	494	412	444	450	1	2	6	12	232	266	360	286	306	263	437	335	32	1	21	18
December	699	395	446	513	680	370	420	490	3	6	6	4	303	340	403	349	306	338	412	352	1	1	2	1
Total (Annual)	2517	2193[4]	2437	2477[5]	2772	2182[4]	2433	2602[5]	10	1[4]	0	5[5]	3562	3740[4]	5461	4512[5]	4297	6393[4]	6118	5208[5]	21	11[4]	12	15[5]

[1] Measured Volume refers to the volumes of water pumped out and measured monthly

[2] Estimated Volumes refers to the volumes of water determined from measuring changes in well water level for the month and converting this change to a monthly volume using the stage-storage relationship or calibration curve developed for the lysimeters

[3] Data not available for period when field simulations were being conducted

[4] Based on 10 months of data

[5] The average of two lysimeters

4.4 Statistical Analysis of Results

To statistically analyze the lysimeter monitoring observations, the concept of "dummy" variables was used in performing a multiple regression analysis. This was necessary because the situation dealt with three distinct levels (i.e. 3 lysimeters) and thus a continuous scale for the variable (lysimeter) could not be set up. In fact, the purpose of conducting the statistical analysis was to assess whether, statistically, the three lysimeters located at each site were responding similarly. A multiple regression analysis using dummy variables could detect separate effects of each site lysimeter on the response.

The model used in the analysis took the following form:

$$Q_{ij} = a + b_1L_1 + b_2L_2 + c_1S_1 + c_2S_2 + c_3S_3 + e \tag{1}$$

where: Q is the observed monthly pump-out volume (L)
i is the monthly observation
j is the lysimeter observed
a is a constant
e is an error term
b_1 and b_2 are coefficients for each lysimeter
c_1 and c_2 and c_3 are coefficients for the season in which the observation was made

L_1 and L_2 are the "dummy" variables for the lysimeter (i.e. if observation Q_{ij} is from lysimeter 1, $L_1 = 1$, $L_2 = 0$, if observation is from lysimeter 2, $L_1 = 0$, $L_2 = 1$, if observation is from L_3, $L_1 = 0$ and $L_2 = 0$).

S_1, S_2 and S_3 are the "dummy" variables for the season (i.e. if observation, Q_{ij} is from the spring, $S_1 = 1$, S_2 and $S_3 = 0$. If the observation is from the summer $S_2 = 1$ S_1 and $S_3 = 0$. If the observations is from the fall $S_3 = 1$, S_1 and $S_2 = 0$. If the observation is from the winter S_1, S_2 and $S_3 = 0$.

The observations were grouped into seasons for specific seasonal lysimeter responses can be expected from the system being modelled. For example, infiltration rates during the spring thaw period are likely to be high. Conversely, little or no infiltration during the winter periods when the ground is frozen can be anticipated. Grouping observations also increased the degrees of freedom in the analysis, improving the confidence in the analysis output. Months were grouped into seasons as follows for the Guelph and Barrie sites.

SEASON	GUELPH	BARRIE
Winter	Jan. - Mar.	Jan. - Feb.
Spring	Apr. - May	Mar. - May
Summer	Jun. - Sept.	Jun. - Sept.
Fall	Oct. - Dec.	Oct. - Dec.

For a more in-depth description of the statistical analysis undertaken here the reader may refer to standard statistics texts such as N. Draper and H. Smith (1981) which describe the "dummy" variable technique in multiple regression.

The hypothesis is that the lysimeters are responding in a similar manner. If this hypothesis is to prove true, the coefficients for L_1 and L_2 in the multiple regression equation will therefore be small in the sense that they would be so close to zero in a normal probability distribution that they could not be regarded as being significantly different from zero. On the other hand, however, it was hypothesized that the responses between seasons would be significantly different. This hypothesis arises from the understanding that essentially no infiltration would be expected during the winter because of frozen ground conditions. Such a condition is significantly different from what could be expected during frost-free periods.

Statsgraphics software was used to perform the multiple regression analysis on the available data. The resulting regression equation for each lysimeter and t-scores are presented in Table 4.2 for both the Guelph and Barrie sites. The constant term included in Table 4.2 is a value representing:

$a+b_2L_2+b_3L_3+e$ for lysimeter 1
$a+b_1L_1+b_3L_3+e$ for lysimeter 2
$a+b_1L_1+b_2L_2+e$ for lysimeter 3

as were described previously in equation (1).

Thus, if differences exist among lysimeters, large values for the "b" coefficients would be expected, giving rise to a large value in the constant term arising from the equation. Alternatively, if the lysimeter were responding similarly (i.e. the hypothesis) then the value for "b" should all be close to zero, forcing this overall constant term to be small as well. A measure of how "small" the constant term is, is reflected in the t-score for this same value. For 28 degrees of freedom as occurs with the available data a t-score which is less than 2.048 can be considered to be small (Crow, E.F. Davis and M. Maxfield, 1960) and thus show the lysimeter to be responding similarly.

Results in Table 4.2 show that the only t-score for the constant term in the regression equation which does not lie below 2.048 is the constant in the equation for Barrie lysimeter 2. All the other lysimeters have a relatively small constant term relative to other coefficients. The reason for the constant term's, significance in the equation for Barrie lysimeter 2 is associated with the fact that, in this case, the constant term is also representing the winter infiltration (i.e. the "a" in the constant term). This lysimeter yielded infiltration during January and February 1990, most likely as a consequence of the fact that the cover was being installed on the site during this same period. Snow could have been trapped between layers of cover as it was applied causing an abnormal amount of infiltration to occur over lysimeter 2. Thus the timing of cover application can help explain the difference in winter readings among lysimeters at the Barrie site. Data being collected through the 1991 winter period will help to determine the significance the winter application had on the lysimeter results in Barrie. Guelph lysimeters however have been statistically shown to be operating similarly with respect to each other.

Table 4.2

Statistical Model of Lysimeter Infiltration Observation

				Co-Efficient					
Site	Lysimeter	Period Analysed	Constant Term	Sp	Su	Sf	t-Score for Constant Term	2-Tailed Test Value For 5% Probability of Exceedence	r^2
Guelph	1	January to December	8.57	361.17	55.71	489.6	0.1835	2.048	0.7674
	2		-10.47	361.17	55.71	489.6	-0.2201	2.048	0.7674
	3		1.904	361.17	55.71	489.6	-0.0408	2.048	0.7674
Barrie	1	January to December	-34.22	786.67	150.67	337.05	-0.3344	2.048	0.6646
	2		225.39	786.67	150.67	337.05	2.1678	2.048	0.6646
	3		123.93	786.67	150.67	337.05	1.2074	2.048	0.6646

5.0 FIELD TESTING OF LYSIMETERS BY SIMULATING INFILTRATION EVENTS

5.1 Field Apparatus and Methodology

An infiltration simulation experiment was conducted at both the Guelph and Barrie sites to further test and verify the reliability of the lysimeters as a tool for measuring through-cover infiltration. Figures 5.1 and 5.2 show the experimental set-up used for the field tests. The set-up involved installing a waterproof barrier around the perimeter of a 4 m x 4 m area within which the lysimeter to be tested was located (see Figure 5.1). A simple irrigation system was installed inside the barriers in order to apply water at a very slow rate. A flowmeter recorded the volumes applied over the 16 m^2 area. This same area was completely covered with plastic throughout the experiment to minimize evaporation/transpiration losses (see Figure 5.2). Initial application rates were estimated using the cover's infiltration and percolation rates as measured using the Guelph infiltrometer and permeameter respectively. These instruments measure the saturated hydraulic conductivity (Kfs) of the soil.

To establish a consistency in initial conditions for the experiments to follow, the soil profile was "wetted-up" and allowed to drain to field capacity. Once field capacity was reached, known volumes of water were applied gradually to the enclosed area.

The soil profile was assumed to have reached field capacity at the point where water stopped coming through the cover after application of water to the cover ceased. This could be observed as the point where the water level recording chart began to show a horizontal line with time. Three separate slow-rate water applications were performed at times when the cover was determined to be at field capacity. The volumes subsequently collected in the lysimeters were compared with the theoretical volumes expected assuming no evaporation/transpiration losses and vertical percolation of the infiltration water applied. This experiment was performed on lysimeter 2 only at both the Guelph and Barrie sites.

Figure 5.1 Apparatus Used in Field Infiltration Experiments

Figure 5.2 Lysimeter was Covered to Prevent Rainfall Inputs and Evapotranspiration Losses during the Experiment. Garbage Bin (in background) Supplied the Irrigation Water for the Tests

5.2 Results from Field Infiltration Tests

Results from the field infiltration simulation tests are provided in Tables 5.1 and 5.2 for Guelph and Barrie respectively. The volume of infiltration water actually collected in the lysimeter's storage zone were quite close to the theoretical volumes. An average of 94 percent of the infiltration volume expected to be captured by the Guelph lysimeter was actually captured over the three trials. Similarly, at Barrie, an average of 99 percent of the infiltration volume expected to be captured was actually measured by the lysimeter for the three trials. Such results instill a high degree of confidence in the lysimeters' ability to measure through-cover infiltration.

Table 5.1

Results From Field Infiltration Testing - Guelph Site

Trial	Volume of Water Applied[1] (L)	Theoretical Volumes of Infiltration Water Available to be Captured (L)	Actual Volume Captured (L)	Percentage of Theoretical
A	303	170	168	99
B	303	170	152	89
C	303	170	161	95
Average	303	170	160	94

Table 5.2

Results From Field Infiltration Testing - Barrie Site

Trial	Volume of Water Applied[1] (L)	Theoretical Volumes of Infiltration Water Available to be Captured (L)	Actual Volume Captured (L)	Percentage of Theoretical
A	613	345	338	98
B	598	336	342	102
C	644	362	349	96
Average	618	348	343	99

[1] Water was applied over a three day period.

6.0 COMPUTER SIMULATION OF COVER INFILTRATION

6.1 Description of HELP Model

The Hydrologic Evaluation of Landfill Performance (HELP) model, developed by the U.S. Environmental Protection Agency was employed in this project's modelling task. Authors of the model describe the HELP model as follows:

> The (HELP) program was developed to facilitate rapid, economical estimation of the amounts of surface run-off, subsurface drainage, and leachate that may be expected to result from the operation of a wide variety of possible designs. The program models the effects of hydrologic processes including precipitation, surface storage, run-off, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage using a quasi-two-dimensional approach.
>
> (Schroeder, P.R., A.C. Gibson and M.D. Smolen, 1983)

A model documentation report and a user's manual have been prepared by the software developers and are available through the U.S. Department of Commerce, National Technical Information Service located at the following address:

U.S. Department of Commerce
National Technical Information Service
Springfield, VA
22161.

The document titles and reference numbers for ordering are:

Schroeder, P.R., A.C. Gibson and M.D. Smolen, 1983. Hydrologic Evaluation of Landfill Performance (HELP) Model: Volume II, Documentation for Version 1. Draft Report. Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH.

Document Number: PB85100832

Schroeder, P.R., J.M. Morgan, T.M. Walski and A.C. Gibson. 1984. The Hydrologic Evaluation of Landfill Performance (HELP) Model. Volume 1, User's Guide for Version 1 Office of Solid Waste. U.S. Environmental Protection Agency, Washington, DC

Document Number: PB85100840

The actual HELP model software can be obtained by contacting the author, Paul R. Schroeder at the following address:

Paul R. Schroeder, Ph.D., P.E.
Environmental Engineer
Environmental Laboratory
U.S. Army Corps. of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS
39180

Ecologistics Limited has made some revisions to the HELP software to enable it to obtain and utilize Ontario-based climatic data. A description of the software changes is outlined in Section 6.2.

While the HELP model is no more complex than a computerized form of a manual tabulation of moisture balance, it combines accepted state-of-the-art mathematical models for computing an accurate water budget over a variety of climatic, soil and vegetative conditions. The purpose of applying this computer model to simulate operation of the lysimeters was to determine the degree of accuracy with which the HELP model could predict volumes of through-cover infiltration.

6.2 Changes Made to the HELP Model

The modifications made to the HELP software from that supplied by the original authors were minor. The source code and call tapes were modified to enable program acceptance of default climatic data from forty Ontario cities and a data file was prepared containing the default climatic data. The revised program source code, executable code and default Ontario climate data can be found on diskette in Appendix F. Revisions to selected pages in the existing software documentation manual and user's manual are also provided.

A list of Ontario cities for which default climatic data is provided can be found in Table 6.1. This default data was obtained for each city from the databank at Environment Canada's Canadian Climate Centre. If available, ten years of precipitation data was transposed to a format which could be used as input for the HELP model. Long term temperature and solar radiation data was also obtained for each station and placed in a suitable format to be read by the HELP model. Table 6.1 identifies the period for which precipitation data is available from the default disk for each Ontario station.

6.3 Results of the HELP Simulation on the Lysimeter Sites

The HELP model was applied to both the Guelph and Barrie sites to simulate through-cover infiltration. The model results were then compared with the lysimeter-measured data to evaluate the HELP model's prediction capability.

The 1990 precipitation and temperature records provided the climatic data for the model. Soil textural analysis information collected during lysimeter construction was used to assist in characterizing the cover's soils. The bulk density data collected during lysimeter installation, along with the saturated hydraulic conductivity readings collected during the field installation, were also tried as input to determine if such field-measured data could improve the simulation results. The results of the HELP simulation are shown in Figures 6.1 and 6.2 for Guelph and Barrie respectively.

The graphs in Figures 6.1 and 6.2 have been prepared in an identical manner to the lysimeter-measured infiltration graphs in Figures 4.3 and 4.4 in order to visually assist in comparing results. For 1990, the Guelph HELP simulation predicted that 30 percent of the year's precipitation passed through the cover. This is quite close to the actual averaged result of 26 percent measured by the lysimeters. This represents an error in annual prediction of 16 percent. The shape of the computer-generated accumulated infiltration curve for the Guelph site was similar to the lysimeter-measured curve except

Table 6.1

Listing of Default Ontario Cities and Associated Years of Data

City	City Code	Period of Default Precipitation Data
Barrie	BARR	79/01 - 88/12
Belleville	BELL	79/01 - 88/12
Brockville	BROC	79/01 - 88/12
Brucefield	BRUC	79/01 - 88/12
Chalk River	CRVR	79/01 - 88/12
Chatham	CHAT	79/01 - 82/12
Cobourg	COBG	79/01 - 88/12
Cornwall	CORN	79/01 - 88/12
Guelph	GUEL	79/01 - 88/12
Hamilton	HAML	79/01 - 88/12
Hanover	HAND	79/01 - 88/12
Huntsville	HUNT	79/01 - 88/12
Kapuskasing	KAPU	79/01 - 88/12
Kenora	KENO	79/01 - 88/12
Kingston	KING	79/01 - 88/12
London	LOND	79/01 - 88/12
Marathon	MARA	79/01 - 83/12
Midland	MIDL	79/01 - 85/12
Mount Forest	MFST	79/01 - 85/12
New Liskard	NLSK	79/01 - 83/12
North Bay	NBAY	79/01 - 88/12
Orangeville	ORAN	79/01 - 88/12
Orillia	ORIL	79/01 - 88/12
Oshawa	OSHA	79/01 - 88/12
Ottawa	OTTA	79/01 - 83/12
Owen Sound	OSND	79/01 - 88/12
Parry Sound	PSND	79/01 - 88/12
Peterborough	PETE	79/01 - 88/12
Petrolia	PETR	79/01 - 88/12
Sault Ste. Marie	SSME	79/01 - 88/12
Simcoe	SIMC	79/01 - 86/12
Smith Falls	SFAL	79/01 - 82/12
Southhampton	SOUT	79/01 - 81/12
Stratford	STRA	79/01 - 88/12
Sudbury	SUDY	79/01 - 88/12
Thunder Bay	TBAY	79/01 - 88/12
Toronto	TORO	79/01 - 88/12
Wawa	WAWA	79/01 - 88/12
Welland	WELL	79/01 - 88/12
Windsor	WIND	79/01 - 88/12

INFILTRATION SIMULATION - GUELPH SITE

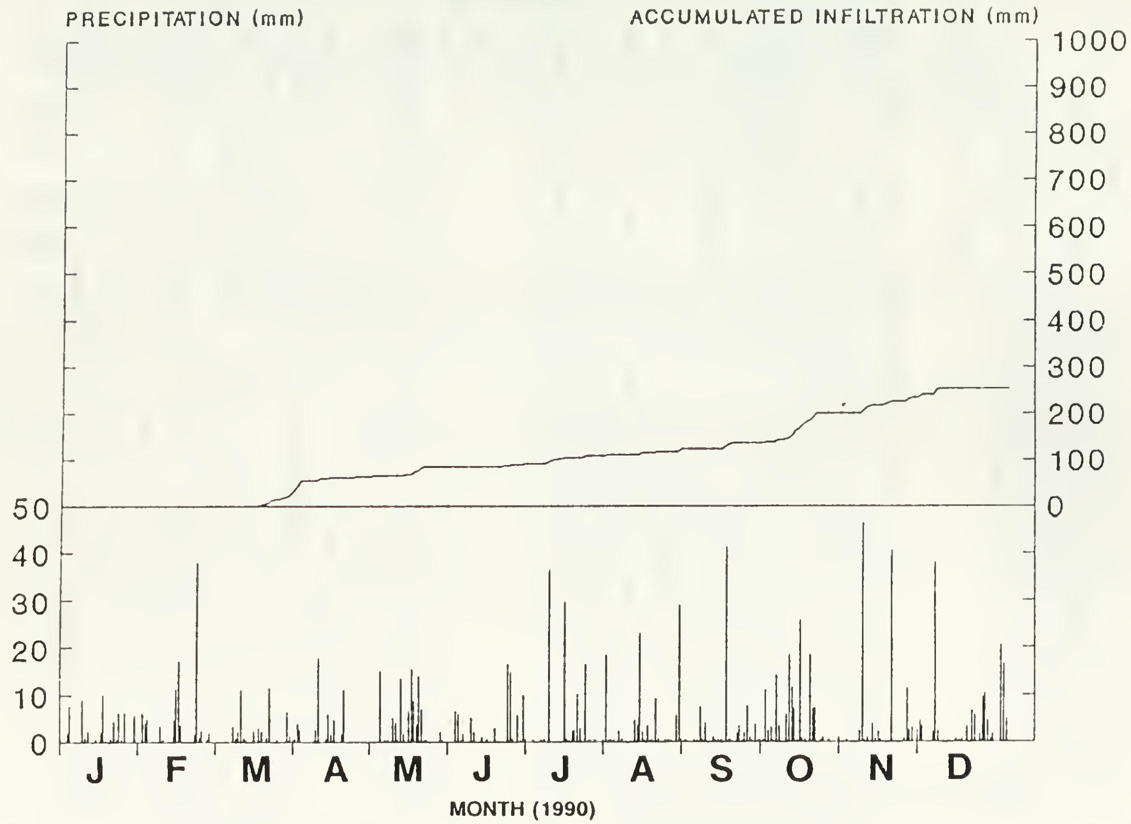


FIGURE 6.1

INFILTRATION SIMULATION - BARRIE SITE

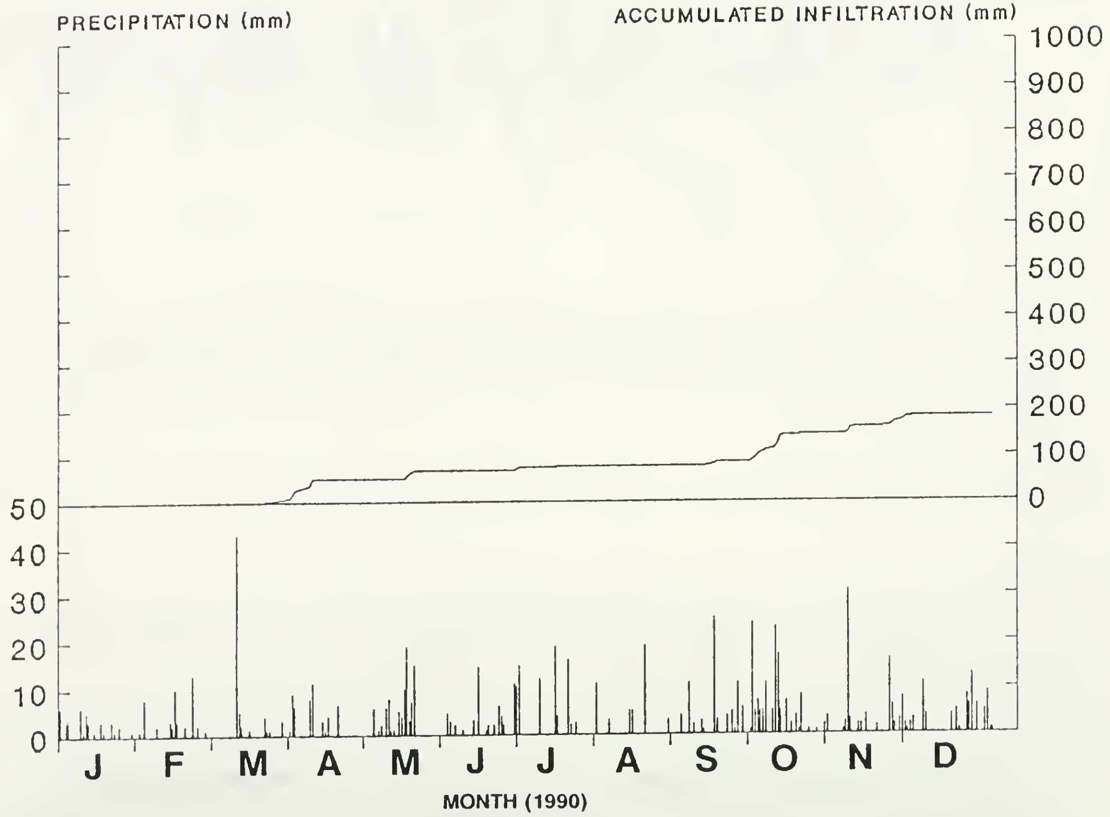


FIGURE 6.2

for the period between mid-March and mid-May. A rapid rate of infiltration was measured by the lysimeters in mid-May but they did not indicate any infiltration to occur in the spring thaw period. Alternatively, the model predicted a rapid recharge in late March and a smaller, yet significant recharge in mid-May during the wet period. The lysimeter also measured a more gradual response to a wet period during the last half of October than did the model. Volumes of infiltration predicted, however, were quite similar to the measured readings.

Computer-generated results for the Barrie site did not as closely match the field observations. While the HELP model predicted that 34 percent of 1990's precipitation passed through the cover, field measurements indicated 67 percent of the precipitation over the lysimeter reached the lysimeter's storage zone. This represents a 49 percent difference between the predicted and the actual. The slope of the modelled curve, in general, was similar to the actual curves. It was the amount of infiltration measured which was in error. There was a delay in response during the spring thaw as well. This delay could be partially a consequence of not being able to model the incomplete cover conditions at the site over the winter. As well, the fact that the HELP model uses average monthly temperature data rather than daily data as input could also limit its ability to predict the thaw period for any particular year.

HELP simulations other than those shown in Figures 6.1 and 6.2 were performed for both the Guelph and Barrie sites. The simulations presented however gave the best results of all the simulations tried using variations in input data. Using available field-measured data such as soil porosity (from the CPN moisture density probe) and saturated hydraulic conductivity (from Guelph permeameter readings) did not improve the predictions made from those made using the model's default values for input parameters. The runoff curve number, a highly subjective number, used by the model to predict runoff volumes, could be adjusted to give the exact annual infiltration volume for the Guelph site. The Barrie site, however, already had essentially no runoff being predicted using the default value generated. Thus adjusting model output using the runoff curve number was not possible for Barrie to bring estimates closer to the actual measurements.

7.0 CONCLUSIONS

The study team has arrived at a number of conclusions in completing the tasks of installing and monitoring the lysimeters and analyzing the infiltration data gathered.

1. A comparison of field simulation results and annual infiltration volumes collected indicates that the lysimeters, as installed, are giving true readings of volumes of infiltration water passing through the overlying cover material.

2. Monthly volumetric measurements are necessary for accurate determination of the amount of through-cover infiltration water collected. Indirect measurements of infiltration volumes obtained by measuring the change in water level height in the storage zone gave 0 to 175 percent errors in monthly volumetric measurements. Daily volumetric measurements are not practical while annual volumetric measurements would require an increase in lysimeter storage zone capacity.

3. The water level recorders can assist in identifying general trends with respect to the rate of through-cover infiltration within any given month. They are not, however, a suitable tool for accurately measuring daily or even monthly volumes of through-cover infiltration.

4. Monthly monitoring of the lysimeters can be set-up to be a routine task for landfill operators.

5. Strict protocol must be followed during construction of the lysimeters to ensure their proper installation and long-term operation.

6. Long-term monitoring of the installed lysimeters is necessary in order to assess the landfill cover's effectiveness in controlling through-cover infiltration.

7. The HELP model's prediction of through-cover infiltration rates at the Guelph site was fair but was poor at the Barrie site. Refinements are needed for the model to produce desired results. Long-term data collected by installed lysimeters is needed to provide data necessary to refine and calibrate an appropriate model.

8.0 RECOMMENDATIONS

The following recommendations are drawn from the results of this study. It is recommended that:

1. The lysimeters constructed and monitored in this study continue to be monitored in order to:

    i) increase the infiltration dataset,

    ii) assess the long-term performance of earthen landfill covers, and

    iii) evaluate the long-term reliability of the lysimeters for use as an infiltration measurement tool.

2. Monthly pump-out of the lysimeter storage zones be the primary means of determining infiltration volumes. Chart recorder data is necessary only if seasonal trends in infiltration rates are desired.

3. Similar lysimeters be installed on other landfills of differing cover textures and configurations to expand the available database on through-cover infiltration.

4. Installation of lysimeters at all sites be consistent, following a prescribed protocol, to enable comparison of data among sites and to simplify monitoring tasks.

5. Landfill operators be trained in the task of routinely monitoring the lysimeter and recording observations in order to economically acquire a large database on through-cover infiltration.

6. The expanded database be used to refine and/or create an appropriate model suitable for use in designing landfill covers.

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APPENDICES

APPENDIX A
LYSIMETER INSTALLATION DETAILS

LIST OF MATERIALS REQUIRED FOR CONSTRUCTING A LYSIMETER

NO.	ITEM	UNIT	QUANTITY
1	3.0 m x 3.0 m x 1.35 m x 1 mm thick (40 mil) High Density PVC Prefabricated Liner	Each	1
2	600 mm inside dia. Class 210 Perforated Heavy Duty Corrugated Polyethylene Pipe (Big "O" tile)	m	12
3	100 mm inside dia. SDF 35 3-Hole Drain Tile (SDF 35 tile)	m	16
4	380 mm Inside Dia. Bell & Spigot Sewer Pipe (for Monitoring Well)	Each	1
5	Mirafi PI50 (or equivalent) Filter Cloth	m^2	100
6	0.6 m x 0.6 m x 5 cm thick Patio Stone	Each	1
7	5 cm x 5 cm x 3.3 m long Spruce Lumber	Each	11
8	1.2 m x 2.4 m x 10 mm thick Spruce Plywood	Each	2
9	Standard Bentonite Sealant	45 kg bag	2
10	Mel-rol (or equivalent) Membrane and Mel-rol (or equivalent) Mastic	m^2 Litres	1.5 2
11	Screened Sand	Tonnes	40
12	2.5 cm to 7.5 cm Clean Stone	Tonnes	7.0
13	Monitoring Well Cover	Each	1

STEPS IN LYSIMETER CONSTRUCTION

MATERIAL PREPARATION

1. Obtain the primary materials required to construct the lysimeter (see list of materials) and have delivered to the construction site.

2. Cut the 600 mm dia. Big "O" tile into 1.2 m and 1.5 m lengths in the most efficient way possible from the standard lengths. When complete, one has four times as many 1.2 m long tiles as 1.5 m long tiles. Thus, for one lysimeter, have eight short tiles and two long tiles.

3. At one end of each 1.5 m long tile cut out a semi-circular section to enable the pipe to fit around the lysimeter's monitoring well (see Figure A-12).

4. Wrap one end of each 600 mm dia. Big "O" tile with a 1.0 m x 1.0 m piece of filter cloth. Secure the filter cloth to the tile with plastic cord. For the longer 1.5 m tiles, wrap the end that was not cut to fit around the monitoring well.

5. Construct the wooden frame used to support the liner during lysimeter construction. The frame is to be 3.0 m x 3.0 m x 1.30 m high (See Figure A-6). Braces are to be placed on the outside of the frame.

6. Cut 1 cm wide by 15 cm long slots at 10 cm spacings around the perimeter of the bottom 60 cm of the monitoring well (See Figure A-11).

7. Cut from the plywood sheets, two smaller sheets with dimensions 0.6 m x 1.4 m and a third smaller sheet that is 0.7 m x 0.7 m. Smooth and round all edges with a belt sander.

8. Measure off a 132 cm length of Mel-rol membrane material and cut from the supply roll. Cut this piece lengthwise into four equally-sized (i.e. 20 cm wide) strips. With the paper side up, mark the midpoint of the width of this strip and draw a centre-line along the length of each strip. Mark off 10 cm intervals along its length. With a utility knife, cut a slit at each 10 cm interval and extend the slit to the midpoint line marked previously. Do the same for all Mel-rol membrane strips. This is then ready to be applied as a component of the mastic Mel-rol/bentonite "skirt".

ON-SITE CONSTRUCTION

9. Set-up a surveying level and tie to a permanent benchmark.

10. Measure and stake the area where the lysimeter is to be installed. For this study, three lysimeters were placed at a 30 m spacing, measured from the centreline of adjacent lysimeter monitoring wells.

11. With a backhoe dig a hole in the landfill cover at the proposed lysimeter location. Take cap moisture and density readings at 15 cm intervals in this hole using a CPN Moisture/Density probe and record for reference when replacing the cover over the lysimeter following its construction (see Figure A-1). If no cap exists at the time of lysimeter construction, this step can be skipped.

12. Excavate a minimum 4.5 m x 4.5 m hole in the landfill cover in the area where the lysimeter is to be installed. Stop when the top garbage layer is reached. Square off and smooth out (see Figure A-2).

13. Record the depth of the cover material.

14. Excavate the garbage material to a depth of 1.2 m below the cover material. Keep the pile of excavated garbage separate from the pile of cover material. Square off and smooth out the hole as best as possible once the required depth is reached.

15. Lay a 3.3 m x 3.3 m section of filtercloth in the bottom of the hole (see Figure A-3).

16. Place 20 cm of screened sand on top of the filter cloth and pack to firm the base. Record the finished grade of this base layer using the surveying equipment (see Figure A-4).

17. Position the previously constructed wooden frame in the excavated hole.

18. Attach the pre-fabricated liner to the wooden frame by folding over the top 5 cm of liner material on the wooden frame and stapling it to the frame (see Figure A-7). Care should be taken to ensure the liner fits squarely on the frame.

19. Place 12 cm of screened sand inside the lysimeter. Fill around the outside of the lysimeter at the same time to maintain vertical liner walls. Pack the sand. Use the surveyor's level to measure sand layer depth and assist in levelling the layer. Record final layer elevation and relate it to a known benchmark.

20. Locate the centre of the lysimeter. Excavate just enough sand to allow the patio stone to be set in place. The patio stone is to be set flush with the sand layer (see Figure A-8). Use the surveying equipment to ensure the patio stone is level and at the proper elevation. Record the patio stone's elevation and relate it to a known benchmark.

21. Cut a 6 m long piece of filter cloth from the 3.3 m wide roll and lay it over the patio stone and sand layer in the lysimeter. Temporarily staple it to the frame to hold it in place (see Figure A-9).

22. Cut two 1.5 m long pieces of filter cloth and drape them over the two remaining sides whose lysimeter walls are exposed. Temporarily staple the filter cloth to the frame.

23. Place four of the 1.2 m long 600 mm dia. Big "O" tiles inside the lysimeter. Position side-by-side in such a manner that the space between adjacent tile is minimized. The filter cloth wrapped end of the pipe is to face the outside wall of the lysimeter (see Figure A-9).

24. Position two 0.6 m x 1.4 m pre-cut sheets of plywood along the outside ends of the 1.2 m long Big "O" tile (see Figure A-9).

25. Place one of the 1.5 m long Big "O" tiles in the storage zone adjacent, to and perpendicular to, the 1.2 m long Big "O" tile already in place. The filter cloth wrapped end of the pipe is to be against the lysimeter liner wall.

26. Cut the monitoring well to the desired final height allowing about 4 ft to extend above the finished landfill cover grade. Set the monitoring well in place, positioning it in the centre of the previously installed patio stone (see Figure A-11).

27. Position the remaining Big "O" tile around the monitoring well in a similar manner described for the tile already in position.

28. Place two 0.6 m x 1.4 m pre-cut sheets of plywood along the ends of the 1.2 m long Big "O" tile just installed.

29. Place the two 0.7 m x 0.7 m pre-cut sheets of plywood along the ends of the 1.5 m long Big "O" tile.

30. Place enough 2.5 cm to 7.5 cm stone along the end of the outside 1.2 m long Big "O" tiles (i.e. where no plywood has been placed) in order to securely hold the Big "O" tile in place.

31. Backfill the outside of the lysimeter hole with sand at the same time the rock is being added to maintain vertical sidewalls.

32. With the storage zone Big "O" tile firmly in position, continue to backfill and pack the outside of the lysimeter with sand maintaining a vertical liner wall at all times until the sand around the outside of the lysimeter reaches the same elevation as the top of the Big "O" tile inside the lysimeter (see Figure A-12).

33. Place the SDF 35 tile in the recesses between the in-place Big "O" tile; cutting as necessary to enable a proper fit (see Figure A-12).

34. Cut a 3.3 m long section from the 3.3 m wide roll of filter cloth. Cut a series of slits in the centre of the filter cloth. Slide the filter cloth over the monitoring well and spread it out over the storage zone tile (see Figure A-12). Securely tie the filter cloth around the monitoring well.

35. Place an 8 cm layer of 2.5 cm to 7.5 cm stone over the filter cloth and level off. Record the final elevation of this stone layer, relating it to the permanent benchmark using the survey equipment (see Figure A-13).

36. Continue to fill and pack the outside of the lysimeter with sand to the same depth as the layers on the inside of the lysimeter (see Figure A-13).

37. Cut a section of filter cloth as before to allow it to slide over the monitoring well and spread it over the stone (see Figure A-14). Securely tie the filtercloth around the monitoring well. Wrap a 10 cm wide strip of Mel-rol membrane around the well to further seal the area.

38. Place and pack a 10 cm layer of sand over the filter cloth. Relate the sand layer to a permanent benchmark using the surveying equipment. Continue to bring the outside of the lysimeter up at the same time (see Figure A-15).

39. Install a Mel-rol/bentonite "skirt" around the monitoring well by completing the following steps:

    - dig a 4 cm wide x 4 cm deep trench around the perimeter of the monitoring well,

    - fill the trench with bentonite, compacting as much as possible,

    - take a pre-cut Mel-rol membrane strip and with the slitted side toward the bottom, peal off the paper backing on the non-slitted half and wrap tightly and securely around the monitoring well,

    - take a second pre-cut Mel-rol membrane strip and wrap as with the first strip, only off-set so that the flaps of the "skirt" of the second strip cover the slits of the first strip (see Figure A-16),

    - Liberally apply the Mel-rol mastic material to the top edge of the Mel-rol membrane to seal the "skirt" (see Figure A-17), and

    - spread bentonite over the "skirt" to complete the seal (see Figure A-18).

40. Remove the filter cloth previously attached to the lysimeter frame from the frame, turning it into the centre of the lysimeter.

41. Apply the previously excavated cover material in 15 cm lifts (see Figure A-19).

42. The density of each lift is checked using the CPN moisture/density probe (see Figure A-22). The lift is compacted until the original cover density (measured when the cover was excavated) is achieved (see Figure A-21).

43. A bentonite seal is placed along the perimeter of the lysimeter to avoid preferential flow along the liner (see Figure A-20).

44. A Mel-rol/bentonite "skirt" is installed around the monitoring well at each point where there is a change in cover material (e.g. at the sand/cover material interface and at the cap material/loam topsoil interface). Follow the installation procedure outlined in step 39.

45. Place bentonite around the well following every second lift (or every 0.3 m).

46. The cover is replaced in 15 cm lifts until the excavated area is again flush with the surrounding cover (see Figures A-23 and A-24). Heavy equipment (backhoe) traffic directly over the lysimeter is possible once 90 cm of cover material has been applied.

47. The lysimeters are filled with water to test for leaks.

48. The lysimeters are pumped down to a pre-set datum.

49. A cover is placed over the monitoring well and the float-and-pulley water-level recorder is installed (see Figures A-24 and A-25).

LYSIMETER CONSTRUCTION STEPS

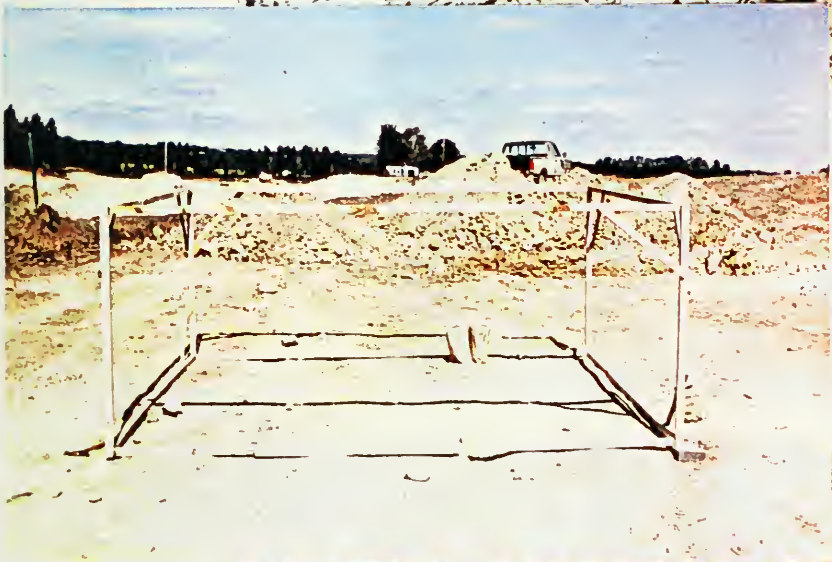
A 1:
MEASURING EXISTING COVER
DENSITY AT 0.3 m (1') INTERVALS

A2:
COVER EXCAVATED
TO GARBAGE LAYER

A3:
GARBAGE REMOVED TO REQUIRED DEPTH. FILTER CLOTH INSTALLED. FIRST LAYER OF SAND APPLIED.

A4:
PREPARING BASE

A5:
THE ELEVATION OF
PERTINENT LYSIMETER
LAYERS RECORDED



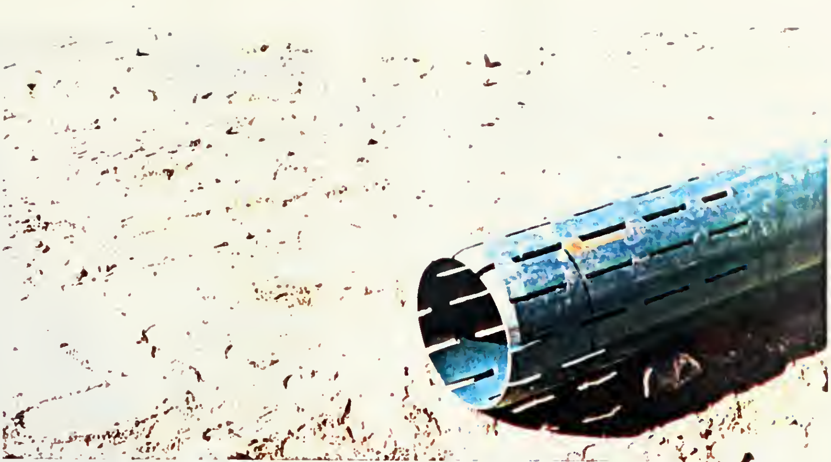
A6:
WOODEN FRAMES
CONSTRUCTED

A7:
FRAME AND LINER
IN POSITION

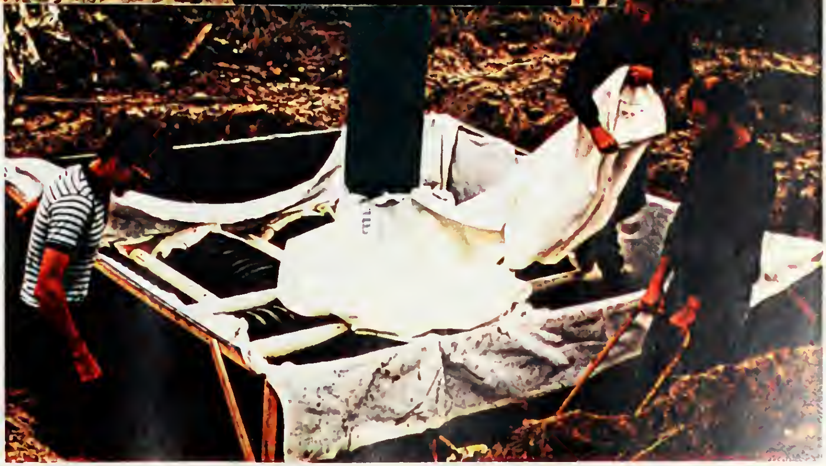
A8:
BOTTOM SAND LAYER IN PLACE.
PATIO STONE POSITIONED

A9:
INSTALLATION OF BIG "O"
STORAGE ZONE TILE.

A10:
MONITORING WELL
SHOWING PRE-CUT SLOTS.
SLOTS EXTEND TO TOP
OF STORAGE ZONE



A11:
POSITIONING
MONITORING WELL.
INSTALLATION-READY
1.5m LONG BIG "O" TILE
SHOWN IN BACKGROUND.



A12:
SDF 35 TILE INSTALLED.
COMPACTING ZONE
OUTSIDE OF LYSIMETER.
INSTALLING A LAYER
OF FILTER CLOTH

A 13:
STONE PLACED OVER FILTER CLOTH.
OUTSIDE OF LYSIMETER BACKFILLED

A 14:
FILTER CLOTH PLACED OVER STONE

A 15:
FINAL SAND LAYER APPLIED.
PERIMETER OF
MONITORING WELL SEALED

A16:
BENTONITE PLACED BELOW
THE TWO MEL-ROL
MEMBRANE LAYERS
SHOWN INSTALLED

A17:
MEL-ROL MASTIC APPLIED

A18:
TOP LAYER OF
BENTONITE APPLIED

A19:
COVER ADDED IN 15 cm LIFTS AND COMPACTED TO ORIGINAL DENSITY

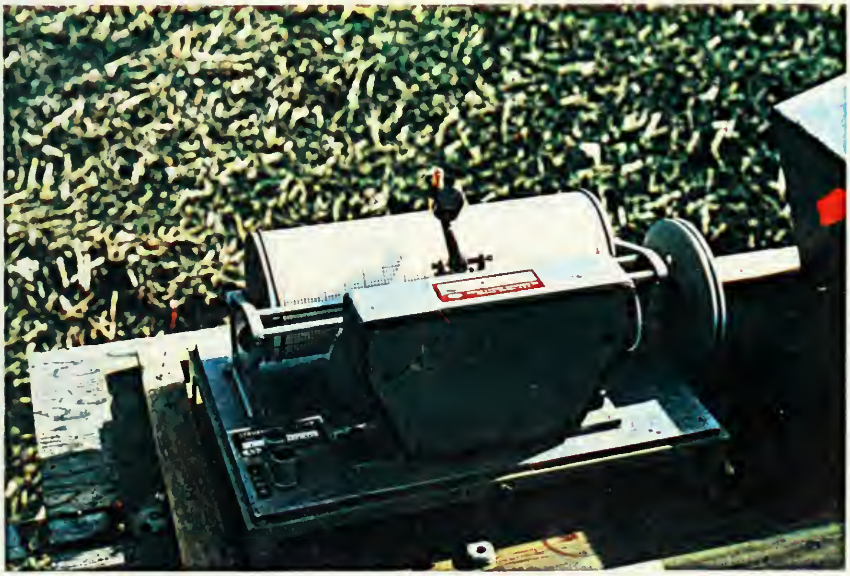
A20:
BENTONITE SEAL PLACED ALONG TOP OF LINER TO PREVENT PREFERENTIAL FLOW ALONG LINER WALL

A21:
COVER COMPACTED
AFTER EACH LIFT

A22:
CPN DENSITY PROBE
USED TO CHECK
DENSITY OF EACH LIFT

A23:
COMPLETED
CONSTRUCTION,
(GUELPH)

A24:
COMPLETED CONSTRUCTION, (BARRIE) SHOWING WELL COVERS



A25:
WATER LEVEL RECORDER INSTALLED

APPENDIX B
STAGE-STORAGE TABLE FOR GUELPH AND BARRIE LYSIMETERS (CALIBRATION TABLE)

TABLE B1
STAGE-STORAGE TABLE FOR GUELPH AND BARRIE LYSIMETERS

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
0	0	0	0	0
1	8.5364	8.536	0.94849	0.948
2	8.5364	17.073	0.94849	1.897
3	8.5364	25.609	0.94849	2.845
4	8.5364	34.146	0.94849	3.794
5	8.5364	42.682	0.94849	4.742
6	8.5364	51.218	0.94849	5.691
7	8.5364	59.755	0.94849	6.639
8	8.5364	68.291	0.94849	7.588
9	8.5364	76.828	0.94849	8.536
10	8.5364	85.364	0.94849	9.485
11	8.5364	93.900	0.94849	10.433
12	8.5364	102.437	0.94849	11.382
13	8.5364	110.973	0.94849	12.330
14	8.5364	119.510	0.94849	13.279
15	8.5364	128.046	0.94849	14.227
16	8.5364	136.582	0.94849	15.176
17	8.5364	145.119	0.94849	16.124
18	8.5364	153.655	0.94849	17.073
19	8.5364	162.192	0.94849	18.021
20	8.5364	170.728	0.94849	18.970
21	8.5364	179.264	0.94849	19.918
22	8.5364	187.801	0.94849	20.867
23	8.5364	196.337	0.94849	21.815
24	8.5364	204.874	0.94849	22.764
25	8.5364	213.410	0.94849	23.712
26	8.5364	221.946	0.94849	24.661
27	8.5364	230.483	0.94849	25.609
28	8.5364	239.019	0.94849	26.558
29	8.5364	247.556	0.94849	27.506
30	8.5364	256.092	0.94849	28.455
31	8.5364	264.628	0.94849	29.403
32	8.5364	273.165	0.94849	30.352
33	8.5364	281.701	0.94849	31.300
34	8.5364	290.238	0.94849	32.249
35	8.5364	298.774	0.94849	33.197
36	8.5364	307.310	0.94849	34.146
37	8.5364	315.847	0.94849	35.094
38	8.5364	324.383	0.94849	36.043
39	8.5364	332.920	0.94849	36.991
40	8.5364	341.456	0.94849	37.940
41	8.5364	349.992	0.94849	38.888
42	8.5364	358.529	0.94849	39.837
43	8.5364	367.065	0.94849	40.785
44	8.5364	375.602	0.94849	41.734
45	8.5364	384.138	0.94849	42.682
46	8.5364	392.674	0.94849	43.630
47	8.5364	401.211	0.94849	44.579
48	8.5364	409.747	0.94849	45.527
49	8.5364	418.284	0.94849	46.476
50	8.5364	426.820	0.94849	47.424
51	8.5842	435.404	0.95380	48.378
52	8.5842	443.988	0.95380	49.332
53	8.5842	452.573	0.95380	50.286
54	8.5842	461.157	0.95380	51.240
55	8.5842	469.741	0.95380	52.193
56	8.5842	478.325	0.95380	53.147

TABLE B1 (continued)

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
57	8.5842	486.909	0.95380	54.101
58	8.5842	495.494	0.95380	55.055
59	8.5842	504.078	0.95380	56.009
60	8.5842	512.662	0.95380	56.962
61	8.5842	521.246	0.95380	57.916
62	8.5842	529.830	0.95380	58.870
63	8.5842	538.415	0.95380	59.824
64	8.5842	546.999	0.95380	60.778
65	8.5842	555.583	0.95380	61.731
66	8.5842	564.167	0.95380	62.685
67	8.5842	572.751	0.95380	63.639
68	8.5842	581.336	0.95380	64.593
69	8.5842	589.920	0.95380	65.547
70	8.5842	598.504	0.95380	66.500
71	8.5842	607.088	0.95380	67.454
72	8.5842	615.672	0.95380	68.408
73	8.5842	624.257	0.95380	69.362
74	8.5842	632.841	0.95380	70.316
75	8.5842	641.425	0.95380	71.269
76	8.5842	650.009	0.95380	72.223
77	8.5842	658.593	0.95380	73.177
78	8.5842	667.178	0.95380	74.131
79	8.5842	675.762	0.95380	75.085
80	8.5842	684.346	0.95380	76.038
81	8.5842	692.930	0.95380	76.992
82	8.5842	701.514	0.95380	77.946
83	8.5842	710.099	0.95380	78.900
84	8.5842	718.683	0.95380	79.854
85	8.5842	727.267	0.95380	80.807
86	8.5842	735.851	0.95380	81.761
87	8.5842	744.435	0.95380	82.715
88	8.5842	753.020	0.95380	83.669
89	8.5842	761.604	0.95380	84.623
90	8.5842	770.188	0.95380	85.576
91	8.5842	778.772	0.95380	86.530
92	8.5842	787.356	0.95380	87.484
93	8.5842	795.941	0.95380	88.438
94	8.5842	804.525	0.95380	89.392
95	8.5842	813.109	0.95380	90.345
96	8.5842	821.693	0.95380	91.299
97	8.5842	830.277	0.95380	92.253
98	8.5842	838.862	0.95380	93.207
99	8.5842	847.446	0.95380	94.161
100	8.5842	856.030	0.95380	95.114
101	8.5968	864.627	0.95520	96.070
102	8.5968	873.224	0.95520	97.025
103	8.5968	881.820	0.95520	97.980
104	8.5968	890.417	0.95520	98.935
105	8.5968	899.014	0.95520	99.890
106	8.5968	907.611	0.95520	100.846
107	8.5968	916.208	0.95520	101.801
108	8.5968	924.804	0.95520	102.756
109	8.5968	933.401	0.95520	103.711
110	8.5968	941.998	0.95520	104.666
111	8.5968	950.595	0.95520	105.622
112	8.5968	959.192	0.95520	106.577
113	8.5968	967.788	0.95520	107.532
114	8.5968	976.385	0.95520	108.487
115	8.5968	984.982	0.95520	109.442

TABLE B1 (continued)

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
116	8.5968	993.579	0.95520	110.398
117	8.5968	1002.176	0.95520	111.353
118	8.5968	1010.772	0.95520	112.308
119	8.5968	1019.369	0.95520	113.263
120	8.5968	1027.966	0.95520	114.218
121	8.5968	1036.563	0.95520	115.174
122	8.5968	1045.160	0.95520	116.129
123	8.5968	1053.756	0.95520	117.084
124	8.5968	1062.353	0.95520	118.039
125	8.5968	1070.950	0.95520	118.994
126	8.5968	1079.547	0.95520	119.950
127	8.5968	1088.144	0.95520	120.905
128	8.5968	1096.740	0.95520	121.860
129	8.5968	1105.337	0.95520	122.815
130	8.5968	1113.934	0.95520	123.770
131	8.5968	1122.531	0.95520	124.726
132	8.5968	1131.128	0.95520	125.681
133	8.5968	1139.724	0.95520	126.636
134	8.5968	1148.321	0.95520	127.591
135	8.5968	1156.918	0.95520	128.546
136	8.5968	1165.515	0.95520	129.502
137	8.5968	1174.112	0.95520	130.457
138	8.5968	1182.708	0.95520	131.412
139	8.5968	1191.305	0.95520	132.367
140	8.5968	1199.902	0.95520	133.322
141	8.5968	1208.499	0.95520	134.278
142	8.5968	1217.096	0.95520	135.233
143	8.5968	1225.692	0.95520	136.188
144	8.5968	1234.289	0.95520	137.143
145	8.5968	1242.886	0.95520	138.098
146	8.5968	1251.483	0.95520	139.054
147	8.5968	1260.080	0.95520	140.009
148	8.5968	1268.676	0.95520	140.964
149	8.5968	1277.273	0.95520	141.919
150	8.5968	1285.870	0.95520	142.874
151	8.5968	1294.467	0.95520	143.830
152	8.5968	1303.064	0.95520	144.785
153	8.5968	1311.660	0.95520	145.740
154	8.5968	1320.257	0.95520	146.695
155	8.5968	1328.854	0.95520	147.650
156	8.5968	1337.451	0.95520	148.606
157	8.5968	1346.048	0.95520	149.561
158	8.5968	1354.644	0.95520	150.516
159	8.5968	1363.241	0.95520	151.471
160	8.5968	1371.838	0.95520	152.426
161	8.5968	1380.435	0.95520	153.382
162	8.5968	1389.032	0.95520	154.337
163	8.5968	1397.628	0.95520	155.292
164	8.5968	1406.225	0.95520	156.247
165	8.5968	1414.822	0.95520	157.202
166	8.5968	1423.419	0.95520	158.158
167	8.5968	1432.016	0.95520	159.113
168	8.5968	1440.612	0.95520	160.068
169	8.5968	1449.209	0.95520	161.023
170	8.5968	1457.806	0.95520	161.978
171	8.5968	1466.403	0.95520	162.934
172	8.5968	1475.000	0.95520	163.889
173	8.5968	1483.596	0.95520	164.844
174	8.5968	1492.193	0.95520	165.799

TABLE B1 (continued)

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
175	8.5968	1500.790	0.95520	166.754
176	8.5968	1509.387	0.95520	167.710
177	8.5968	1517.984	0.95520	168.665
178	8.5968	1526.580	0.95520	169.620
179	8.5968	1535.177	0.95520	170.575
180	8.5968	1543.774	0.95520	171.530
181	8.5968	1552.371	0.95520	172.486
182	8.5968	1560.968	0.95520	173.441
183	8.5968	1569.564	0.95520	174.396
184	8.5968	1578.161	0.95520	175.351
185	8.5968	1586.758	0.95520	176.306
186	8.5968	1595.355	0.95520	177.262
187	8.5968	1603.952	0.95520	178.217
188	8.5968	1612.548	0.95520	179.172
189	8.5968	1621.145	0.95520	180.127
190	8.5968	1629.742	0.95520	181.082
191	8.5968	1638.339	0.95520	182.038
192	8.5968	1646.936	0.95520	182.993
193	8.5968	1655.532	0.95520	183.948
194	8.5968	1664.129	0.95520	184.903
195	8.5968	1672.726	0.95520	185.858
196	8.5968	1681.323	0.95520	186.814
197	8.5968	1689.920	0.95520	187.769
198	8.5968	1698.516	0.95520	188.724
199	8.5968	1707.113	0.95520	189.679
200	8.5968	1715.710	0.95520	190.634
201	8.5842	1724.294	0.95380	191.588
202	8.5842	1732.878	0.95380	192.542
203	8.5842	1741.463	0.95380	193.496
204	8.5842	1750.047	0.95380	194.450
205	8.5842	1758.631	0.95380	195.403
206	8.5842	1767.215	0.95380	196.357
207	8.5842	1775.799	0.95380	197.311
208	8.5842	1784.384	0.95380	198.265
209	8.5842	1792.968	0.95380	199.219
210	8.5842	1801.552	0.95380	200.172
211	8.5842	1810.136	0.95380	201.126
212	8.5842	1818.720	0.95380	202.080
213	8.5842	1827.305	0.95380	203.034
214	8.5842	1835.889	0.95380	203.988
215	8.5842	1844.473	0.95380	204.941
216	8.5842	1853.057	0.95380	205.895
217	8.5842	1861.641	0.95380	206.849
218	8.5842	1870.226	0.95380	207.803
219	8.5842	1878.810	0.95380	208.757
220	8.5842	1887.394	0.95380	209.710
221	8.5842	1895.978	0.95380	210.664
222	8.5842	1904.562	0.95380	211.618
223	8.5842	1913.147	0.95380	212.572
224	8.5842	1921.731	0.95380	213.526
225	8.5842	1930.315	0.95380	214.479
226	8.5842	1938.899	0.95380	215.433
227	8.5842	1947.483	0.95380	216.387
228	8.5842	1956.068	0.95380	217.341
229	8.5842	1964.652	0.95380	218.295
230	8.5842	1973.236	0.95380	219.248
231	8.5842	1981.820	0.95380	220.202
232	8.5842	1990.404	0.95380	221.156
233	8.5842	1998.989	0.95380	222.110

TABLE B1 (continued)

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
234	8.5842	2007.573	0.95380	223.064
235	8.5842	2016.157	0.95380	224.017
236	8.5842	2024.741	0.95380	224.971
237	8.5842	2033.325	0.95380	225.925
238	8.5842	2041.910	0.95380	226.879
239	8.5842	2050.494	0.95380	227.833
240	8.5842	2059.078	0.95380	228.786
241	8.5842	2067.662	0.95380	229.740
242	8.5842	2076.246	0.95380	230.694
243	8.5842	2084.831	0.95380	231.648
244	8.5842	2093.415	0.95380	232.602
245	8.5842	2101.999	0.95380	233.555
246	8.5842	2110.583	0.95380	234.509
247	8.5842	2119.167	0.95380	235.463
248	8.5842	2127.752	0.95380	236.417
249	8.5842	2136.336	0.95380	237.371
250	8.5842	2144.920	0.95380	238.324
251	8.5364	2153.456	0.94849	239.273
252	8.5364	2161.993	0.94849	240.221
253	8.5364	2170.529	0.94849	241.170
254	8.5364	2179.066	0.94849	242.118
255	8.5364	2187.602	0.94849	243.067
256	8.5364	2196.138	0.94849	244.015
257	8.5364	2204.675	0.94849	244.964
258	8.5364	2213.211	0.94849	245.912
259	8.5364	2221.748	0.94849	246.861
260	8.5364	2230.284	0.94849	247.809
261	8.5364	2238.820	0.94849	248.758
262	8.5364	2247.357	0.94849	249.706
263	8.5364	2255.893	0.94849	250.655
264	8.5364	2264.430	0.94849	251.603
265	8.5364	2272.966	0.94849	252.552
266	8.5364	2281.502	0.94849	253.500
267	8.5364	2290.039	0.94849	254.449
268	8.5364	2298.575	0.94849	255.397
269	8.5364	2307.112	0.94849	256.346
270	8.5364	2315.648	0.94849	257.294
271	8.5364	2324.184	0.94849	258.243
272	8.5364	2332.721	0.94849	259.191
273	8.5364	2341.257	0.94849	260.140
274	8.5364	2349.794	0.94849	261.088
275	8.5364	2358.330	0.94849	262.037
276	8.5364	2366.866	0.94849	262.985
277	8.5364	2375.403	0.94849	263.934
278	8.5364	2383.939	0.94849	264.882
279	8.5364	2392.476	0.94849	265.831
280	8.5364	2401.012	0.94849	266.779
281	8.5364	2409.548	0.94849	267.728
282	8.5364	2418.085	0.94849	268.676
283	8.5364	2426.621	0.94849	269.625
284	8.5364	2435.158	0.94849	270.573
285	8.5364	2443.694	0.94849	271.522
286	8.5364	2452.230	0.94849	272.470
287	8.5364	2460.767	0.94849	273.419
288	8.5364	2469.303	0.94849	274.367
289	8.5364	2477.840	0.94849	275.316
290	8.5364	2486.376	0.94849	276.264
291	8.5364	2494.912	0.94849	277.212
292	8.5364	2503.449	0.94849	278.161

TABLE B1 (continued)

WELL LEVEL ABOVE DATUM (mm)	INCREMENTAL VOLUME (L)	ACCUMULATED VOLUME (L)	INCREMENTAL INFILTRATION (mm)	ACCUMULATED DEPTH OF INFILTRATION (mm)
293	8.5364	2511.985	0.94849	279.109
294	8.5364	2520.522	0.94849	280.058
295	8.5364	2529.058	0.94849	281.006
296	8.5364	2537.594	0.94849	281.955
297	8.5364	2546.131	0.94849	282.903
298	8.5364	2554.667	0.94849	283.852
299	8.5364	2563.204	0.94849	284.800
300	8.5364	2571.740	0.94849	285.749

APPENDIX C
MEASURED MONTHLY VOLUME OF THROUGH-COVER INFILTRATION

TABLE C-1
Measured Monthly Volumes of Through-Cover Infiltration

	GUELPH SITE					BARRIE SITE				
Month	Total Precipitation (mm)	Lysimeter 1 (mm)	Lysimeter 2 (mm)	Lysimeter 3 (mm)	Average (mm)	Total Precipitation (mm)	Lysimeter 1 (mm)	Lysimeter 2 (mm)	Lysimeter 3 (mm)	Average (mm)
January	58.3	0	0	0	0	40	0	3.1	0	1.0
February	100.0	0	0	0	0	47	0	66.9	0	22.3
March	45.4	0	0	0	0	60.2	47.6	163.3	116.4	109.1
April	51.5	8.9	28.9	13.8	17.2	49.8	69.4	125.8	113.7	103.0
May	97.9	56.1	61.1	72	63.1	87.8	47.	124.4	83.1	85.1
June	71.4	6.7	4.7	4.4	5.3	81.2	27.7	30.0	25.6	27.8
July	10.9	2.9	3.7	3.3	3.3	66.4	26.8	32.2	29.4	29.5
August	86 3	7.3	17.4	15.8	13.5	35.0	31.8	24.7	26.4	27.6
September	89 4	7.4	10.7	8	8.7	105.2	23.6	13.2	21.8	19.5
October	125.4	58.1	57.1	57.2	57.4	108.4	62.4	44.2	105.6	70 7
November	87.0	54.6	44.9	46.7	48.7	90.2	25.8	29.6	40.0	31.8
December	129.5	77.7	43.9	49.6	57.1	74.6	33.7	37.8	44.8	38.8
TOTAL	1063.0	279.7	272.4	270.8	274.3	845.8	396.7	695.2	606.8	566.2
Fraction of Total Precipitation (Jan 1/90 to Dec 31/90)		0.26	0.26	0.25	0.26	-	0.47	0.82	0.72	0.67
Fraction of Total Precipitation (Jun 1/90 to Dec 31/90)		0.30	0.26	0.26	0.27	-	0.41	0.38	0.52	0.44

Note: Volumes of infiltration measured were converted to a depth of water over the lysimeters 9m² surface area.

APPENDIX D

WATER LEVEL RECORDER DATA

TABLE D-1: GUELPH LYSIMETER #1
TABLE D-2: GUELPH LYSIMETER #2
TABLE D-3: GUELPH LYSIMETER #3

TABLE D-4: BARRIE LYSIMETER #4
TABLE D-5: BARRIE LYSIMETER #5
TABLE D-6: BARRIE LYSIMETER #6

TABLE D-1: GUELPH LYSIMETER #1

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0.00	0.00
FEB 1	32.5	0.00	0.00
VOL = 0 L			
FEB 1	32.5	0.00	0.00
MAR 1	60.5	0.00	0.00
VOL = 0 L			
MAR 1	60.5	0.00	0.00
APR 5	95.5	0.00	0.00
VOL = 0 L			
APR 5	95.5	0.00	0.00
	100.5	0.00	0.00
	101.39	3.30	3.13
	105.22	10.00	9.49
	111.56	20.80	19.73
MAY 1	121.5	25.80	24.47
VOL = 80 L PUMPED OUT			
MAY 1	121.5	0.00	24.47
	124.5	5.00	29.21
	138.5	10.00	33.96
	144.7	57.50	79.31
	148.8	63.30	84.85
JUN 1	152.5	63.30	84.85
VOL = 505 L PUMPED OUT			
JUN 1	152.5	0.00	84.85
	156.5	5.00	89.59
	164.25	8.30	92.72
	172.3	10.00	94.33
JUL 2	183.5	10.00	94.33
VOL = 60 L PUMPED OUT			
JUL 2	183.5	0.00	94.33
JUL 30	211.5	3.30	97.46
VOL = 26 L PUMPED OUT			
JUL 30	211.5	0.00	97.46
	226.1	0.80	98.22
	232.5	5.40	102.58
AUG 31	243.5	7.90	104.96
VOL = 66 L PUMPED OUT			
AUG 31	243.5	0	104.96
	247.7	1.7	106.57
	248.4	2.5	107.33
	257.4	3.8	108.56
OCT 1	274.5	3.8	108.56
VOL = 67 L PUMPED OUT			
OCT 1	274.5	0	108.56
	275.2	0.4	108.94
	281.3	20	127.53
	287.9	37.5	144.13
	289	42.5	148.87
	295.8	65	170.56
	300.4	70	175.33
	303.4	70.8	176.09
OCT 31	304.5	72.5	177.71
VOL = 523 L PUMPED OUT			
OCT 31	304.5	0	177.71
	307.7	1.7	179.32
	309.2	3.8	181.31
	311.2	4.2	181.69
	317.4	16.7	193.55
	320.8	20.8	197.44
	321.5	21.7	198.29

TABLE D-1 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
	325.4	24.6	201.04
	327.9	26.3	202.66
	329.6	28.3	204.55
	333.2	36.7	212.52
	334.8	47.5	222.76
	336	51.7	227.02
DEC 3	337.5	57.5	232.55
VOL = 491 L PUMPED OUT			
DEC 3	337.5	0	232.55
	341.1	10	242.03
	342.3	10.8	242.79
	343.8	17.5	249.15
	344.5	20	251.52
	346.1	26.7	257.87
	349.4	33.3	264.13
	351.9	40	270.49
	353.1	44.2	274.47
	354	50	280.24
	355.4	60.8	290.54
	359.5	70	299.32
	360.5	73.3	302.46
	361.7	75	304.09
DEC 31	365.5	79.2	308.09
VOL = 699 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

TABLE D-2: GUELPH LYSIMETER #2

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0.00	0.00
FEB 1	32.5	0.00	0.00
VOL = 0 L			
FEB 1	32.5	0.00	0.00
MAR 1	60.5	0.00	0.00
VOL = 0 L			
MAR 1	60.5	0.00	0.00
APR 5	95.5	0.00	0.00
VOL = 0 L			
APR 5	95.5	0.00	0.00
	101	0.00	0.00
	102.8	15.00	14.23
	104.7	18.30	17.36
	106.7	23.30	22.10
	110.8	27.50	26.08
	113.2	33.30	31.59
MAY 1	121.5	35.00	33.20
VOL = 260 L PUMPED OUT			
MAY 1	121.5	0.00	33.20
	136.5	0.00	33.20
	137.9	16.70	49.04
	142.2	55.00	85.66
	144.7	64.20	94.43
JUN 1	152.5	69.20	99.20
VOL = 550 L PUMPED OUT			
JUN 1	152.5	0.00	99.20
JUL 2	183.5	2.50	101.57
VOL = 42 L PUMPED OUT			
JUL 2	183.5	0.00	101.57
JUL 30	211.5	3.30	104.70
VOL = 33 L PUMPED OUT			
ACTUALLY JUL 30 IS JULY 28 AS STARTED SIMULATION ON 28 EXTRAPOLATED TOGET TO JULY 30		AVERAGE INFILTRATION FOR LYSIMETERS 1 & 3 FOR THIS SIMULATION PERIOD WAS 18.1 mm	
RESTARTED #2 SEP 21 IT WILL NEED TIME TO RETURN TO NORMAL FOLLOWING TEST. DONT EXPECT TO BE SAME AS OTHERS IMMEDIATELY			
SEP 21	264.5	0	122.80
	265.4	2.9	125.55
	266.6	4.2	126.78
	272	8.3	130.67
OCT 1	274.5	9.2	131.53
VOL = 96 L PUMPED OUT			
OCT 1	274.5	0	131.53
	286.1	21.7	152.11
	293.2	36.7	166.34
	298.6	46.7	175.82
OCT 31	304.5	53.3	182.37
VOL = 514 L PUMPED OUT			
OCT 31	304.5	0	182.37
	305	5.8	187.87
	308.1	17.5	198.97
	312.3	25	206.08
	316.7	27.5	208.45

TABLE D-2 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
	321.7	34.2	214.81
	326.4	38.3	218.70
	331	42.5	222.68
DEC 3	337.5	48.3	228.18
VOL = 404 L PUMPED OUT			
DEC 3	337.5	0	228.18
	344	5	232.92
	347.1	8.3	236.05
	350.2	15.8	243.17
	353.7	21.6	248.67
	358.9	32.5	259.01
DEC 31	365.5	43.3	269.25
VOL = 395 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

TABLE D-3: GUELPH LYSIMETER #3

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0.00	0.00
FEB 1	32.5	0.00	0.00
VOL = 0 L			
FEB 1	32.5	0.00	0.00
MAR 1	60.5	0.00	0.00
VOL = 0 L			
MAR 1	60.5	0.00	0.00
APR 5	95.5	0.00	0.00
VOL = 0 L			
APR 5	95.5	0.00	0.00
	106.5	5.00	4.74
	115.5	10.00	9.49
MAY 1	121.5	12.50	11.86
VOL = 124 L PUMPED OUT			
MAY 1	121.5	0.00	11.86
	137.5	3.30	14.99
	140.5	36.70	46.67
	142.1	60.80	69.85
	146.3	71.70	80.24
	150.3	76.50	84.82
JUN 1	152.5	76.50	84.82
VOL = 648 L PUMPED OUT			
JUN 1	152.5	0.00	84.82
JUL 2	183.5	5.40	89.94
VOL = 40 L PUMPED OUT			
JUL 2	183.5	0.00	89.94
JUL 30	211.5	4.20	93.93
VOL = 30 L PUMPED OUT			
JUL 30	211.5	0.00	93.93
	215.9	1.00	94.88
	227.6	4.00	97.72
	236.4	13.00	106.26
AUG 31	243.5	16.00	109.10
VOL = 142 L PUMPED OUT			
AUG 31	243.5	0.00	109.10
	252.7	3.30	112.23
	256.1	3.30	112.23
	267.7	5.80	114.60
	268.5	7.50	116.21
OCT 1	274.5	8.3	116.97
VOL = 72 L PUMPED OUT			
OCT 1	274.5	0	116.97
	285	25	140.68
	288.8	35	150.17
	298.2	52.5	167.04
	301	55.8	170.19
	303.3	58.3	172.58
OCT 31	304.5	60	174.20
VOL = 515 L PUMPED OUT			
OCT 31	304.5	0	174.20
	305.5	1.7	175.81
	308.2	3.3	177.33
	310.1	5	178.94
	312.7	7.5	181.31
	316.1	15	188.43
	319.6	20.8	193.93
	322.4	25.8	198.67
	325.6	29.2	201.90
	329.2	34.2	206.64
	332.3	39.2	211.38

TABLE D-3 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
	334.6	45.8	217.64
DEC 3	337.5	51.7	223.51
VOL = 420 L PUMPED OUT			
DEC 3	337.5	0	223.51
	340.7	3.3	226.64
	342.3	7.5	230.62
	343	8.3	231.38
	344.9	11.7	234.61
	345.7	15	237.74
	348	18.3	240.87
	349.6	20	242.48
	352.2	25.8	247.98
	354.2	32.5	254.34
	355.4	35	256.71
	356.1	35	256.71
	358.6	40	261.45
	360.1	43.3	264.58
	362.1	48.3	269.32
	363.3	47.5	268.56
DEC 31	365.5	49.2	270.18
VOL = 446 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

TABLE D-4: BARRIE LYSIMETER #1

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0	0
	16.5	0	0
FEB 3	34.5	0	0
VOL = 0 L			
FEB 3	34.5	0	0
MAR 3	62.5	0	0
VOL = 0 L			
MAR 3	62.5	0	0
	67.6	0	0
	70.1	9.5	9
	71.5	24.2	23
	76.5	38.3	36.3
	85.4	70	66.4
	90	90.8	86.1
	91.7	98.3	93.2
APR 3	93.5	104.1	98.7
VOL = 428 L PUMPED OUT			
APR 3	93.5	0	98.7
	98.7	10.8	108.9
	101.6	19.1	116.8
	104.2	37.5	134.3
	107.5	48.3	144.5
	109.6	60.8	156.7
	112.4	73.3	168.7
	116.3	81.7	176.6
	118.6	89.2	183.8
APR 30	120.5	100	194.1
VOL = 625 L PUMPED OUT			
APR 30	120.4	0	194.1
	125.1	15	208.3
	129.1	30	222.6
	135.7	38.3	230.4
	142.5	53.3	244.9
	145.8	58.3	249.7
	150.2	70.8	261.6
JUN 2	153.5	76.7	267.3
VOL = 431 L PUMPED OUT			
JUN 2	153.5	0	267.3
	154.2	5.8	272.8
	157.3	7.5	274.4
	165.2	12.5	279.2
	173.1	15.8	282.3
JUN 30	181.5	22.5	288.6
VOL = 249 L PUMPED OUT			
JUN 30	181.5	22.5	288.6
JUL 30	211.5	52.5	317.3
VOL = 234 L PUMPED OUT			
JUL 30	211.5	0	317.3
	217.6	7	323.9
	231.2	15	331.5
	236.8	24	340.1
	238	28	343.9
SEP 1	244.5	39.7	355
VOL = 286 L PUMPED OUT			
SEP 1	244.5	0	355.0
	265.5	19.2	373.2
SEP 29	272.5	22.5	376.3
VOL = 212 L PUMPED OUT			
SEP29	272.5	0	376.3
	275.1	1.7	377.9

TABLE D-4 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
	277.2	1.7	377.9
	282.7	13.3	388.9
	284.5	19.2	394.5
	286.3	28.8	403.6
VANDALISM (DATA LOST)			
		estimated using pumped out data	
NOV 3	307.5		442.3
VOL = 562 L PUMPED OUT			
NOV 3	307.5	0	442.3
	309	2.5	444.7
	312.1	5.8	447.8
	315.1	5.8	447.8
	317.2	10	451.8
	318.7	10.8	452.5
	326.1	15	456.5
	329.2	21.7	462.9
	330.7	27.9	468.8
	332.9	32.5	473.1
DEC 1	335.5	35.8	476.3
VOL =232 L PUMPED OUT			
DEC1	335.5	0	476.3
	337.9	3.3	479.4
	342.3	7.5	483.4
	345.8	11.7	487.4
	347.1	12.5	488.2
	349.8	15	490.5
	351.2	19.2	494.5
	353.7	23.3	498.4
	356	24.2	499.3
	356.7	26.7	501.6
	359.1	30	504.8
DEC 30	364.5	35.8	510.3
VOL =303 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

TABLE D-5: BARRIE LYSIMETER #2

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0	0
	16.5	0	0
FEB 3	34.5	2.5	2.4
VOL = 28 L PUMPED OUT			
FEB 3	34.5	2.5	2.4
	39.7	6.7	6.4
	45.7	19.2	18.2
	52.3	27.5	26.1
	53	47.5	45.1
	55.4	65	62
	59.4	77.5	73.9
	61.1	80.8	77.1
MAR 3	62.5	81.7	77.9
VOL = 602 L PUMPED OUT			
MAR 3	62.5	0	77.9
	66.5	10	87.4
	72.6	17.5	94.5
	73.9	19.2	96.1
	75	35.8	111.9
	76.2	60.8	135.9
	78	85.8	159.7
	79.2	111.7	184.6
	80.8	137.5	209.2
	81.4	150	221.2
	84.9	177.5	247.4
	91	198.3	267.3
APR 3	93.5	206.7	275.3
VOL = 1470 L PUMPED OUT			
APR 3	93.5	0	275.3
	95.6	16.7	291.1
	97.1	29.2	303
	100	47.5	320.4
	107	80	351.6
	111.2	105	375.6
	115.4	131.7	401.1
APR 30	120.5	151.7	420.2
VOL = 1132 L PUMPED OUT			
APR 30	120.5	0	420.2
	124.28	33	451.5
	129.44	64.1	481.3
	134.78	84.2	500.5
	139.59	100	515.6
	143.03	124.2	538.8
	147.33	140.8	554.7
JUN 2	153.5	151.6	565
VOL = 1120 L PUMPED OUT			
JUN 2	153.5	0	565
	160.5	7.5	572.1
	172.5	12.5	576.9
JUN 30	181.5	23.3	587.1
VOL = 270 L PUMPED OUT			
JUN 30	181.5	23.3	587.1
	188.7	27.4	591
	192.6	37.5	600.6
	200.6	49.1	611.8
JUL 30	211.5	57.5	619.8
VOL = 290 L PUMPED OUT			
JUL 30	211.5	0	619.8
	237.9	22.5	641.1
	240.9	22.9	641.5

TABLE D-5 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
	242.4	25	643.5
SEP 1	244.5	25	643.5
VOL = 222 L PUMPED OUT			
SEP 1	244.5	0	643.5
	246.3	3.3	646.5
	251.3	7.9	650.6
	261.4	10.8	653.2
	263.6	13.3	655.5
SEP 21	264.5	13.3	655.5
VOL = 119 L PUMPED OUT			
STARTED SIMULATION SEPT 21. ENDED SIMULATION OCT 20.	AVERAGE SIMULATION FOR LYSIMETERS 1&3 FOR SIMULATION PERIOD WAS 65.7 mm		721.2
OCT 20	293.5	0	721.2
	294.5	9.6	729.8
	296	20	739.2
	299.7	35.8	753.4
	303	43.3	760.2
	305.7	47.5	763.9
NOV 3	307.5	49.2	765.5
VOL = 398 L PUMPED OUT			
NOV 3	307.5	0	765.5
	312.6	0.8	766.2
	315	1.7	767.0
	317.7	6.7	771.5
	319.2	6.7	771.5
	320.1	7.5	772.2
	323.2	10	774.5
	329.5	20	783.5
	330.4	25	788.0
	334	29.2	791.8
DEC 1	335.5	32.5	794.7
VOL = 266 L PUMPED OUT			
DEC 1	335.5	0	794.7
	336.5	9.2	803.0
	338.7	18.3	811.2
	340.2	21.7	814.2
	341.5	23.3	815.7
	344.8	27.5	819.4
	350.7	29.2	821.0
	352.3	30.8	822.4
	354.3	31.7	823.2
	355.9	34.2	825.5
	357.3	35	826.2
	360.8	36.7	827.7
DEC 30	364.5	41.7	832.2
VOL = 340 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

TABLE D-6: BARRIE LYSIMETER #3

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
JAN 1	1.5	0	0
	16.5	0	0
FEB 3	34.5	0	0
VOL = 0 L			
FEB 3	34.5	0	0
MAR 3	62.5	0	0
VOL = 0 L			
MAR 3	62.5	0	0
	73.9	5	4.7
	75.3	29.2	27.7
	77.4	70.8	67.5
	79.7	98.3	93.8
	83.9	126.7	121
	88.3	140.8	134.5
APR 3	93.5	154.2	147.3
VOL = 1048 L PUMPED OUT			
APR 3	93.5	0	147.3
	98.6	18.3	164.7
	103.7	40	185.2
	106.9	61.7	206.1
	111	80.8	224.4
	115.1	101.7	244.4
	118	121.7	263.5
APR 30	120.5	137.5	278.6
VOL = 1023 L PUMPED OUT			
APR 30	120.5	0	278.6
	123.1	15.8	293.6
	128	30.8	307.8
	132.1	37.5	314.2
	140.4	45	321.3
	142.8	47.5	323.7
	146.6	70.8	346.1
	150.7	86.6	361.2
JUN 2	153.5	92.5	366.8
VOL = 748 L PUMPED OUT			
JUN 2	153.5	0	366.8
	160.5	14.2	380.3
	169.3	20.8	386.5
JUN 30	181.6	28.3	393.6
VOL = 230 L PUMPED OUT			
JUN 30	181.6	28.3	393.6
	183.6	31.6	396.8
	187.9	34.1	399.1
	196.1	45	409.5
	204.5	54.1	418.4
JUL 30	211.5	60.8	424.8
VOL = 265 L PUMPED OUT			
JUL 30	211.5	0	424.8
	227.5	18	441.9
SEP 1	244.5	30	453.3
VOL = 238 L PUMPED OUT			
SEP 1	244.5	0	453.3
	251.2	7.5	460.4
	253.6	11.7	464.4
	261.6	16.7	469.1
	263.8	16.7	469.1
	266.9	20	472.3
	268.4	20.4	472.6
	268.8	20.8	473
SEP 29	272.5	22.1	474.3

TABLE D-6 continued

DATE (1990)	JULIAN DAY	WELL LEVEL (mm) (from charts)	VOL. OF INFILTRATION ADJUSTED FOR STORAGE ZONE POROSITY (mm) (accumulative)
VOL = 196 L PUMPED OUT			
SEP 29	272.5	0	474.3
	276.4	2.5	476.7
	277.3	4.6	478.7
	278.8	5.8	479.8
	279.7	8.3	482.2
	283.4	25	498.0
	284.2	27.9	500.8
	286.3	49.2	521.0
VANDALISM (data lost)			
		estimated using pumped out data	
NOV 3	307.5		585.3
VOL = 950 L PUMPED OUT			
NOV 3	307.5	0	585.3
	308.2	2.5	587.7
	309.1	3.3	588.4
	310.4	7.1	592.0
	313.1	7.5	592.4
	315.7	11.7	596.4
	316.9	13.3	597.9
	321.8	27.5	611.4
	326.5	37.5	620.9
	327.3	38.3	621.6
	327.8	40	623.2
	329.1	41.6	624.8
	330.6	45	628.0
	331.9	45	628.0
	333.1	48.3	631.1
DEC 1	335.5	50.8	633.8
VOL = 360 L PUMPED OUT			
DEC 1	335.5	0	633.8
	337.9	6.6	640.1
	343.5	20	652.8
	351	31.7	663.9
	354.6	35.8	667.8
	358.9	40	671.7
	360.5	45	676.5
DEC 30	364.5	48.3	679.6
VOL = 403 L PUMPED OUT			

NOTE: Volume of infiltration is expressed as a depth of water over the lysimeter's 9 sq. m surface area.

APPENDIX E
STATSGRAPHICS STATISTICAL ANALYSIS: DATA STRUCTURE AND OUTPUT

TABLE E-1
Data Used In Statistical Analysis Of The Guelph Lysimeters

VOL.	L1	L2	L3	W	SP	SU	F
0.	1.	0.	0	1	0.	0.	0.
0.	1.	0.	0	1	0.	0.	0.
0.	1.	0.	0	1	0.	0.	0.
80.	1.	0.	0	0	1.	0.	0.
505.	1.	0.	0	0	1.	0.	0.
60.	1.	0.	0	0	0.	1.	0.
26.	1.	0.	0	0	0.	1.	0.
66.	1.	0.	0	0	0.	1.	0.
67.	1.	0.	0	0	0.	1.	0.
523.	1.	0.	0	0	0.	0.	1.
491.	1.	0.	0	0	0.	0.	1.
699.	1.	0.	0	0	0.	0.	1.
0.	0.	1.	0	1	0.	0.	0.
0.	0.	1.	0	1	0.	0.	0.
0.	0.	1.	0	1	0.	0.	0.
260.	0.	1.	0	0	1.	0.	0.
550.	0.	1.	0	0	1.	0.	0.
42.	0.	1.	0	0	0.	1.	0.
33.	0.	1.	0	0	0.	1.	0.
514.	0.	1.	0	0	0.	0.	1.
404.	0.	1.	0	0	0.	0.	1.
395.	0.	1.	0	0	0.	0.	1.
0.	0.	0.	1	1	0.	0.	0.
0.	0.	0.	1	1	0.	0.	0.
0.	0.	0.	1	1	0.	0.	0.
124.	0.	0.	1	0	1.	0.	0.
648.	0.	0.	1	0	1.	0.	0.
40.	0.	0.	1	0	0.	1.	0.
30.	0.	0.	1	0	0.	1.	0.
142.	0.	0.	1	0	0.	1.	0.
72.	0.	0.	1	0	0.	1.	0.
515.	0.	0.	1	0	0.	0.	1.
420.	0.	0.	1	0	0.	0.	1.
446.	0.	0.	1	0	0.	0.	1.

Where: VOL is the monthly pumped out volume of infiltration from the Guelph lysimeters
L1 is the "dummy" variable representing lysimeter 1
L2 is the "dummy" variable representing lysimeter 2
L3 is the "dummy" variable representing lysimeter 3
W is the "dummy" variable representing the winter season
SP is the "dummy" variable representing the spring season
SU is the "dummy" variable representing the summer season
F is the "dummy" variable representing the fall season

TABLE E-2
Data Used In Statistical Analysis Of The Barrie Lysimeters

VOL.	L1	L2	L3	W	SP	SU	F
0.	1.	0.	0.	1.	0.	0.	0.
0.	1.	0.	0.	1.	0.	0.	0.
428.	1.	0.	0.	0.	1.	0.	0.
625.	1.	0.	0.	0.	1.	0.	0.
431.	1.	0.	0.	0.	1.	0.	0.
249.	1.	0.	0.	0.	0.	1.	0.
234.	1.	0.	0.	0.	0.	1.	0.
286.	1.	0.	0.	0.	0.	1.	0.
212.	1.	0.	0.	0.	0.	1.	0.
562.	1.	0.	0.	0.	0.	0.	1.
232.	1.	0.	0.	0.	0.	0.	1.
303.	1.	0.	0.	0.	0.	0.	1.
28.	0.	1.	0.	1.	0.	0.	0.
602.	0.	1.	0.	1.	0.	0.	0.
1470.	0.	1.	0.	0.	1.	0.	0.
1132.	0.	1.	0.	0.	1.	0.	0.
1120.	0.	1.	0.	0.	1.	0.	0.
270.	0.	1.	0.	0.	0.	1.	0.
290.	0.	1.	0.	0.	0.	1.	0.
222.	0.	1.	0.	0.	0.	1.	0.
266.	0.	1.	0.	0.	0.	0.	1.
340.	0.	1.	0.	0.	0.	0.	1.
0.	0.	0.	1.	1.	0.	0.	0.
0.	0.	0.	1.	1.	0.	0.	0.
1048.	0.	0.	1.	0.	1.	0.	0.
1023.	0.	0.	1.	0.	1.	0.	0.
748.	0.	0.	1.	0.	1.	0.	0.
230.	0.	0.	1.	0.	0.	1.	0.
265.	0.	0.	1.	0.	0.	1.	0.
238.	0.	0.	1.	0.	0.	1.	0.
196.	0.	0.	1.	0.	0.	1.	0.
950.	0.	0.	1.	0.	0.	0.	1.
360.	0.	0.	1.	0.	0.	0.	1.
403.	0.	0.	1.	0.	0.	0.	1.

Where: VOL is the monthly pumped out volume of infiltration from the Barrie lysimeters
L1 is the "dummy" variable representing lysimeter 1
L2 is the "dummy" variable representing lysimeter 2
L3 is the "dummy" variable representing lysimeter 3
W is the "dummy" variable representing the winter season
SP is the "dummy" variable representing the spring season
SU is the 'dummy" variable representing the summer season
F is the "dummy" variable representing the fall season

STATSGRAPHICS OUTPUT - GUELPH LYSIMETERS

Model fitting results for: LYSIMETER 3

```
-------------------------------------------------------------------------------
Independent variable              coefficient  std. error      t-value  sig.level
-------------------------------------------------------------------------------
CONSTANT
REGRESS.11                           1.903846   46.704426       0.0408     0.9678
REGRESS.12                           6.666667   46.407887       0.1437     0.8868
REGRESS.sp                         -12.378205   49.012192      -0.2526     0.8025
REGRESS.su                         361.166667   59.912325       6.0283     0.0000
REGRESS.f                           55.705128   52.546585       1.0601     0.2982
                                   489.666667   53.587212       9.1378     0.0000
-------------------------------------------------------------------------------
R-SQ. (ADJ.) = 0.7674  SE=      113.675644  MAE=      61.053922  DurbWat=  2.679
Previously:    0.0000             0.000000             0.000000            0.000
34 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

Model fitting results for: LYSIMETER 2

```
-------------------------------------------------------------------------------
Independent variable              coefficient  std. error      t-value  sig.level
-------------------------------------------------------------------------------
CONSTANT
REGRESS.11                         -10.474359   47.582956      -0.2201     0.8274
REGRESS.13                          19.044872   49.012192       0.3886     0.7005
REGRESS.sp                          12.378205   49.012192       0.2526     0.8025
REGRESS.su                         361.166667   59.912325       6.0283     0.0000
REGRESS.f                           55.705128   52.546585       1.0601     0.2982
                                   489.666667   53.587212       9.1378     0.0000
-------------------------------------------------------------------------------
R-SQ. (ADJ.) = 0.7674  SE=      113.675644  MAE=      61.053922  DurbWat=  2.679
Previously:    0.7674           113.675644            61.053922            2.679
34 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

Model fitting results for: LYSIMETER 1

```
-------------------------------------------------------------------------------
ndependent variable               coefficient  std. error      t-value  sig.level
-------------------------------------------------------------------------------
ONSTANT
EGRESS.12                            8.570513   46.704426       0.1835     0.8557
EGRESS.13                          -19.044872   49.012192      -0.3886     0.7005
EGRESS.sp                           -6.666667   46.407887      -0.1437     0.8868
EGRESS.su                          361.166667   59.912325       6.0283     0.0000
EGRESS.f                            55.705128   52.546585       1.0601     0.2982
                                   489.666667   53.587212       9.1378     0.0000
-------------------------------------------------------------------------------
-SQ. (ADJ.) = 0.7674  SE=       113.675644  MAE=      61.053922  DurbWat=  2.679
reviously:    0.7674            113.675644            61.053922            2.679
4 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

STATSGRAPHICS OUTPUT - BARRIE LYSIMETERS

Model fitting results for: LYSIMETER 3

```
------------------------------------------------------------------------------
Independent variable                coefficient  std. error    t-value  sig.level
------------------------------------------------------------------------------
CONSTANT                             123.930616  102.641145     1.2074     0.2374
REGRESSB.L1                             -158.25   88.502414    -1.7881     0.0846
REGRESSB.L2                          101.458153   93.045109     1.0904     0.2848
REGRESSB.SP                          786.666667  114.256125     6.8851     0.0000
REGRESSB.SU                          150.671706  110.134707     1.3681     0.1822
REGRESSB.F                           337.048596  117.276202     2.8740     0.0077
------------------------------------------------------------------------------
R-SQ. (ADJ.) = 0.6646  SE=     216.785755  MAE=     155.590718  DurbWat=  1.497
Previously:    0.7674          113.675644            61.053922            2.679
34 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

Model fitting results for: LYSIMETER 2

```
------------------------------------------------------------------------------
Independent variable                coefficient  std. error    t-value  sig.level
------------------------------------------------------------------------------
CONSTANT                             225.388769  103.971677     2.1678     0.0388
REGRESSB.L1                         -259.708153   93.045109    -2.7912     0.0094
REGRESSB.13                         -101.458153   93.045109    -1.0904     0.2848
REGRESSB.SP                          786.666667  114.256125     6.8851     0.0000
REGRESSB.SU                          150.671706  110.134707     1.3681     0.1822
REGRESSB.F                           337.048596  117.276202     2.8740     0.0077
------------------------------------------------------------------------------
R-SQ. (ADJ.) = 0.6646  SE=     216.785755  MAE=     155.590718  DurbWat=  1.497
Previously:    0.6646          216.785755           155.590718            1.497
34 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

Model fitting results for: LYSIMETER 1

```
------------------------------------------------------------------------------
Independent variable                coefficient  std. error    t-value  sig.level
------------------------------------------------------------------------------
CONSTANT                             -34.319384  102.641145    -0.3344     0.7406
REGRESSB.L2                          259.708153   93.045109     2.7912     0.0094
REGRESSB.13                              158.25   88.502414     1.7881     0.0846
REGRESSB.SP                          786.666667  114.256125     6.8851     0.0000
REGRESSB.SU                          150.671706  110.134707     1.3681     0.1822
REGRESSB.F                           337.048596  117.276202     2.8740     0.0077
------------------------------------------------------------------------------
R-SQ. (ADJ.) = 0.6646  SE=     216.785755  MAE=     155.590718  DurbWat=  1.497
Previously:    0.6646          216.785755           155.590718            1.497
34 observations fitted, forecast(s) computed for 0 missing val. of dep. var.
```

APPENDIX F

- DESCRIPTION OF MODIFICATIONS
- DEFAULT ONTARIO CLIMATIC DATA
- THE HELP SOFTWARE (Diskettes)

DESCRIPTION OF MODIFICATIONS MADE TO THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) PROGRAM

October 1990
Ecologistics Limited

The Hydrologic Evaluation of Landfill Performance (HELP) program was modified to accept Canadian data. This modification consisted of:

Modifying Tape 8
- added Ontario cities
- now accepts 80 columns of data
- this tape is used for displaying available cities and states

Creating Tape 7
- 4 character state abbreviations
- 1 state per record
- first record is count of number of states
- added "ONTA" to list of states

Creating Tape 19
- 4 character city abbreviations
- 1 city per record
- first record is count of number of cities
- added Ontario cities

Modifying Tape 9
- climatic data for cities
- first record contained state and city abbreviation (eg. "ALAS ANNE" for Annette, Alaska
- followed by 185 records of climate data (37 records per year x 5 years)
- followed by other data
- modified first record to contain record count for climate data. If this value is missing it is assumed that there are 185 records. This value must be a multiple of 37, and between 74 and 740
  For example:
  "ALAS ANNE" - 185 records (5 years) for Annette, Alaska
  "ONTA BARR 370" - 370 records (10 years) for Barrie, Ontario
  "ONTA BELL 74" - 74 records (2 years) for Belleville, Ontario

The following pages replace pages 8, 9 and 22 in the User's Manual and page 40 and 42 in the Documentation Report.

The user should enter YES if it is desired to build a new data file of soil data from the default soil texture data, and NO if it is desired to enter soil data manually during the run or edit previously entered soil or design data.

If the user answers 3 or 5 questions 1.1, the program transfers controls to subroutine II. SIMULA (question 11.1).

If the user answers 4 to question 1.1., the run is halted and the following message is printed:

1.4 ENTER RUN HELP TO RERUN PROGRAM OR ENTER LOGOFF TO LOGOFF COMPUTER SYSTEM.

DEFAULT CLIMATOLOGIC DATA (2. DCDATA)

If the user specified that default climatologic data would be used (a YES response to question 1.2), the program first asks if the user wants a list of cities for which default climatologic data are stored.

2.1 DO YOU WANT A LIST OF DEFAULT CITIES? ENTER YES OR NO.

A YES response will result in the program printing a list (Table 1) of the 142 cities for which climatologic data sets are stored. Regardless of the answer to 2.1, the following question is printed:

2.2 ENTER NAME OF STATE OF INTEREST.

The user need only enter the first four characters of the state name or ONTA for Ontario data. Some states have no cities for which climatologic data are stored. For these, the program responds:

2.3 THERE ARE NO DEFAULT VALUES FOR __________.

and control is returned to question 2.1. In that case, the user must enter climatologic data manually or use the default data for a nearby city from a neighbouring state.

Once the state name is entered, the user must enter the name of the city for which climatologic data are to be used in response to:

2.4 ENTER NAME OF CITY OF INTEREST

The user can only select form the 142 cities given in response to question 2.1. This table is reproduced in Section 3 as Table 1. For the Ontario cities, type in the four letter abbreviation for the city as indicated in Table 1.

If the name of the city is not found in the default climatologic database, the program responds with statement 2.3 and asks question 2.1. If the user wants a listing of the cities, the program produces a listing of the cities and returns to question 2.2; else, the program returns to question 2.4. Due to the large size of the Ontario data file, it can take a long time for the program to find and load the data. Be patient, it will eventually retrieve the data.

account in the manual selection of a curve number. This approach to runoff estimation is made possible by considering only daily precipitation totals, and not the intensity, duration and distribution of individual rainfall events (storms).

Percolation and vertical water routing are modelled using Darcy's Law for saturated flow with modifications for unsaturated conditions. Lateral drainage is computed analytically from a linearized Boussinesq equation corrected to agree with numerical solutions of the nonlinearized form for the range of design specifications used in hazardous waste landfills. Evapotranspiration is estimated by a modified Penman method adjusted for limiting soil moisture conditions. Detailed solution methods for all hydrologic processes are presented in the program documentation (5).

DATA REQUIREMENTS

The HELP program requires climatologic, soil, and design data. However, sufficient default climatologic and soil data are internally available to satisfy the needs of many users. Although the model contains default climatologic and soil data, these data should not be used unless they have been examined and verified to be representative of the site under study. In all cases, the user should attempt to acquire data specific to the site and use these available data before supplementing with default data. The basic data requirements and input options are briefly discussed below. Step-by-step instructions for entering data into the program are given in Section 4, and complete input/output listings for three examples are presented in Section 6.

Climatologic Data

Climatologic data, including daily precipitation in inches, mean monthly temperatures in °F, mean monthly insolation (solar radiation) in langleys, leaf area indices, and winter cover factors, may be entered manually or selected form built-in default data files. Default climatologic data are available for only 142 cities; therefore, none of these cities may be representative of the study site. The precipitation database is also limited to only five years of daily records which may not be representative since the period of record could have been unusually wet or dry. It is also highly recommended to run the simulation for more than five years to examine the design under the range of possible climatologic conditions.

Default Data Option--

Default climatologic data for the U.S. consisting of five years (usually 1974-78) of observed daily precipitation and one set of values for mean monthly temperature, mean monthly insolation, and leaf area index for each of the cities listed in Table 1 are built into the program. Ontario default data is similar in content. but can contain up to ten years (1979-1988) of precipitation data. These data may be accessed and used simply by giving the appropriate responses to straightforward program queries as described in Section 4.

It is important to understand that, while the program requires daily precipitation, temperature, and insolation data, it interpolates for average daily temperature and insolation from mean monthly data. Therefore, even system at the base of the landfill, percolation from the base of the landfill, head on top of the barrier soil layer at the base of the landfill, and soil water content of the evaporative zone. Output of monthly totals is also optional. The totals of the daily values for each month are given for the following variables: precipitation, runoff, evapotranspiration, lateral drainage from each subprofile, and percolation through the bottom of each sub-profile. Output of daily values and monthly totals are output options only when detailed output is requested. Detailed output always includes annual totals of the variables listed for monthly output and a summary. The summary of the simulation is always produced, and includes monthly and annual averages, and peak daily values for the variables listed for the optional output along with several other variables. The variables are described later in this section of the documentation.

INPUT VARIABLES

Three types of input are used in the model: climatologic, soil and design data. Tables 5 and 7 list the climatologic input variables for the manual and default options, respectively. The manual and default input variables for soil characteristics are given in Tables 8 and 9, respectively, and Table 10 lists the design variables. The HELP User's Guide (19) provides a more complete discussion of input requirements.

Manual Climatologic Input

Climatologic variables are shown in Table 5. The user may specify from 2 to 20 years of daily precipitation values, one year for each year of simulation desired. Twelve monthly mean temperatures and twelve monthly mean solar radiation values may be specified for one year or each year of simulation. Thirteen leaf area indices, the corresponding Julian dates, and a winter cover factor may also be specified for one year or each year of simulation. Only one evaporative zone depth may be specified for the simulation.

Default Climatologic Input

The model stores default climatologic data for 142 cities. For U.S. sites, by specifying the desired state and city from Table 6, the user is supplied daily precipitation data for years 1974 through 1978, one set of monthly mean temperature and solar radiation values, and sets of leaf area indices and winter cover factors for a good row crop and an excellent stand of grass. Actual leaf area indices and winter cover factor used during the simulation are selected or corrected from the default sets after the vegetation type is specified; the correction factors are given in Table 3. The input variables are summarized in Table 7.

Ontario data supplied is identical to the U.S. data with the exception that up to 10 years (1979-1988) of precipitation data is available for many of the stations listed.

Manual Soil Data Input

Soil characteristics must be specified for each layer in the design. The required characteristics, listed in Table 8, include porosity, field capacity, wilting point, evaporation coefficient, and hydraulic conductivity.

TABLE 1. LISTING OF DEFAULT CITIES AND STATES

- Alaska
  - Annette
  - Bethel
  - Fairbanks
- Arizonia
  - Flagstaff
  - Phoenix
  - Tucson
- Arkansas
  - Little Rock
- California
  - Fresno
  - Los Angeles
  - Sacramento
  - San Diego
  - Santa Maria
- Colorado
  - Denver
  - Grand Junction
- Connecticut
  - Bridgeport
  - Hartford
  - New Haven
- Florida
  - Jacksonville
  - Miami
  - Orlando
  - Tallahassee
  - Tampa
  - W. Palm Beach
- Georgia
  - Atlanta
  - Watkinsville
- Hawaii
  - Honolulu
- Idaho
  - Boise
  - Pocatello
- Illinois
  - Chicago
  - E St. Louis
- Indiana
  - Indianapolis
- Iowa
  - Des Moines
- Kansas
  - Dodge City
  - Topeka
- Kentucky
  - Lexington
- Louisiana
  - Lake Charles
  - New Orleans
  - Shreveport
- Maine
  - Augusta
  - Bangor
  - Caribou
  - Portland
- Massachusetts
  - Boston
  - Plainfield
  - Worcester
- Michigan
  - E. Lansing
  - Sault Ste. Marie
- Minnesota
  - St Cloud
- Missouri
  - Columbia
- Montana
  - Glasgow
  - Great Falls
- Nebraska
  - Grand Island
  - North Omaha
- Nevada
  - Ely
  - Las Vegas
- New Hampshire
  - Concord
  - Nashua
- New Jersey
  - Edison
  - Seabrock
- New Mexico
  - Albuquerque
- New York
  - Central Park
  - Ithaca
  - New York City
  - Schenectady
  - Syracuse
- North Carolina
  - Greensboro
- North Dakota
  - Bismarck
- Ohio
  - Cincinnati
  - Cleveland
  - Columbus
  - Put-in-Bay
- Oklahoma
  - Oklahoma City
  - Tulsa
- Oregon
  - Astoria
  - Medford
  - Portland
- Pennsylvania
  - Philadelphia
  - Pittsburgh
- Rhode Island
  - Providence
- South Carolina
  - Charleston
- South Dakota
  - Rapid City
- Tennessee
  - Knoxville
  - Nashville
- Texas
  - Brownsville
  - Dallas
  - El Paso
  - Midland
  - San Antonio
- Utah
  - Cedar City
  - Salt Lake City
- Vermont
  - Burlington
  - Montpelier
  - Rutland
- Virginia
  - Lynchburg
  - Norfolk
- Washington
  - Pullman
  - Seattle
  - Yakima
- Wisconsin
  - Madison
- Wyoming
  - Cheyenne
  - Lander
- Puerto Rico
  - San Juan
- Ontario (Canada)
  - Barrie (BARR)
  - Belleville (BELL)
  - Brockville (BROC)
  - Brucefield (BRUC)
  - Chalk River (CRVR)
  - Chatham (CHAT)
  - Cobourg (COBG)
  - Cornwall (CORN)
  - Guelph (GUEL
  - Hamilton (HAML)
  - Hanover (HANO)
  - Huntsville (HUNT
  - Kapuskasing (KAPU)
  - Kenora (KENO)
  - Kingston (KING)
  - London (LOND)
  - Marathon (MARA)
  - Midland (MIDL)
  - Mount Forest (MFST)
  - New Liskard (NLSK)
  - North Bay (NBAY)
  - Orangeville (ORAN
  - Orillia (ORIL)
  - Oshawa (OSHA
  - Ottawa (OTTA)
  - Owen Sound (OSND)
  - Parry Sound (PSND)
  - Peterborough (PETE)
  - Petrolia (PETR)
  - Sault Ste. Marie (SSME
  - Simcoe (SIMC)
  - Smith Falls (SFAL)
  - Southhampton (SOUT)
  - Stratford (STRA)
  - Sudbury (SUDY)
  - Thunder Bay (TBAY)
  - Toronto (TORO)
  - Wawa (WAWA
  - Welland (WELL
  - Windsor (WIND

TABLE 6. LISTING OF DEFAULT CITIES AND STATES

Default Data is Provided Only for the Following Cities and States

- Alaska
  - Annette
  - Bethel
  - Fairbanks

- Arizona
  - Flagstaff
  - Phoenix
  - Tucson

- Arkansas
  - Little Rock

- California
  - Fresno
  - Los Angeles
  - Sacramento
  - San Diego
  - Santa Maria

- Colorado
  - Denver
  - Grand Junction

- Connecticut
  - Bridgeport
  - Hartford
  - New Haven

- Florida
  - Jacksonville
  - Miami
  - Orlando
  - Tallahassee
  - Tampa
  - W. Palm Beach

- Georgia
  - Atlanta
  - Watkinsville

- Hawaii
  - Honolulu

- Idaho
  - Boise
  - Pocatello

- Illinois
  - Chicago
  - E. St. Louis

- Indiana
  - Indianapolis

- Iowa
  - Des Moines

- Kansas
  - Dodge City
  - Topeka

- Kentucky
  - Lexington

- Louisiana
  - Lake Charles
  - New Orleans
  - Shreveport

- Maine
  - Augusta
  - Bangor
  - Caribou
  - Portland

- Massachusetts
  - Boston
  - Plainfield
  - Worcester

- Michigan
  - E. Lansing
  - Sault Ste. Marie

- Minnesota
  - St. Cloud

- Missouri
  - Columbia

- Montana
  - Glasgow
  - Great Falls

- Nebraska
  - Grand Island
  - North Omaha

- Nevada
  - Ely
  - Las Vegas

- New Hampshire
  - Concord
  - Nashua

- New Jersey
  - Edison
  - Seabrook

- New Mexico
  - Albuquerque

- New York
  - Central Park
  - Ithaca
  - New York City
  - Schenectady
  - Syracuse

- North Carolina
  - Greensboro

- North Dakota
  - Bismarck

- Ohio
  - Cincinnati
  - Cleveland
  - Columbus
  - Put-in-Bay

- Oklahoma
  - Oklahoma City
  - Tulsa

- Oregon
  - Astoria
  - Medford
  - Portland

- Pennsylvania
  - Philadelphia
  - Pittsburgh

- Rhode Island
  - Providence

- South Carolina
  - Charleston

- South Dakota
  - Rapid City

- Tennessee
  - Knoxville
  - Nashville

- Texas
  - Brownsville
  - Dallas
  - El Paso
  - Midland
  - San Antonio

- Utah
  - Cedar City
  - Salt Lake City

- Vermont
  - Burlington
  - Montpelier
  - Rutland

- Virginia
  - Lynchburg
  - Norfolk

- Washington
  - Pullman
  - Seattle
  - Yakima

- Wisconsin
  - Madison

- Wyoming
  - Cheyenne
  - Lander

- Puerto Rico
  - San Juan

- Ontario (Canada)
  - Barrie (BARR)
  - Belleville (BELL)
  - Brockville (BROC)
  - Brucefield (BRUC)
  - Chalk River (CRVR)
  - Chatham (CHAT)
  - Cobourg (COBG)
  - Cornwall (CORN)
  - Guelph (GUEL)
  - Hamilton (HAML)
  - Hanover (HAND)
  - Huntsville (HUNT)
  - Kapuskasing (KAPU)
  - Kenora (KENO)
  - Kingston (KING)
  - London (LOND)
  - Marathon (MARA)
  - Midland (MIDL)
  - Mount Forest (MFST)
  - New Liskard (NLSK)
  - North Bay (NBAY)
  - Orangeville (ORAN)
  - Orillia (ORIL)
  - Oshawa (OSHA)
  - Ottawa (OTTA)
  - Owen Sound (OSND)
  - Parry Sound (PSND)
  - Peterborough (PETE)
  - Petrolia (PETR)
  - Sault Ste. Marie (SSME
  - Simcoe (SIMC)
  - Smith Falls (SFAL)
  - Southhampton (SOUT)
  - Stratford (STRA)
  - Sudbury (SUDY)
  - Thunder Bay (TBAY)
  - Toronto (TORO)
  - Wawa (WAWA)
  - Welland (WELL)
  - Windsor (WIND)